DESIGN, SIMULATION AND DEVELOPMENT OF AN UNITERRUPTIBLE SWITCHED-MODE POWER SUPPLY FOR PERSONAL COMPUTERS

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in partial fulfillment of the requirements
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By

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CERTIFICATE

This is to certify that the work contained in this thesis entitled "**Design, Simulation and Development of an Uninterruptible Switched-Mode Power Supply for Personal Computers**", by **G. Srikanth**, has been carried out under my supervision and that this work has not been submitted elsewhere for any degree.

11/05/05

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(SRIKANTH GADDE)

Dedicated
to my
beloved parents

Abstract

This thesis introduces the concept of an uninterruptible switched-mode power supply which performs the combined functions of an uninterruptible power supply and a switched-mode power supply, using only one DC-DC power conversion stage, to overcome the shortcomings of traditional SMPS and UPS combination. The key element of the proposed power supply is a DC-DC Converter with input from battery. The DC-DC Converter uses full bridge topology with high frequency operation to provide good performance and reduced size. The power supply is one of the most crucial components for personal computers. The traditional way to protect computers against power failure is to add an uninterruptible power supply preceding the input of switched-mode power supply. This combination is highly inefficient due to multiple power conversion stages owing to separate design of SMPS and UPS. This project aims at bridging this gap by design, simulation & hardware implementation of a simple, efficient and compact power supply for personal computers which integrates the external UPS into the computer switching power supply to form an uninterruptible switched-mode power supply. This design offers substantial improvement in efficiency, size and cost over the conventional cascade of UPS and SMPS due to single power conversion stage, high frequency switching and removal of design redundancy. The operation, design, simulation and experimental implementation of the converter are presented.

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Nomenclature

UPS	Uninterruptible power supply
SMPS	Switched-mode power supply
PC	Personal computer
UC	Unitrode corporation
USMPS	Uninterruptible switched mode power supply
CPU	Central processing unit
PWM	Pulse width modulation
AC	Alternating current
DC	Direct Current
IC	Integrated circuit
MOSFET	Metal oxide semiconductor field effect transistor
SWG	Standard wire gauge
TTL	Transistor transistor logic
IR	International rectifier
ESR	Equivalent series resistance

Chapter 1

Introduction

1.1 Motivation

Computer system has become very important all over the world. They are capable of doing complicated work such as intensive and complex computation, word processing etc. Power supply is the most important part of any electrical system. When the main power input fails, the computer cannot support normal operation and shuts down. As a result, all working data is lost if they are not saved previously. Therefore, an UPS system is designed to protect data loss and prevent any output interruption after the main power input fails suddenly. Presently, people use UPS for power supply backup and SMPS inside CPU box to have controlled DC supplies as per requirements.

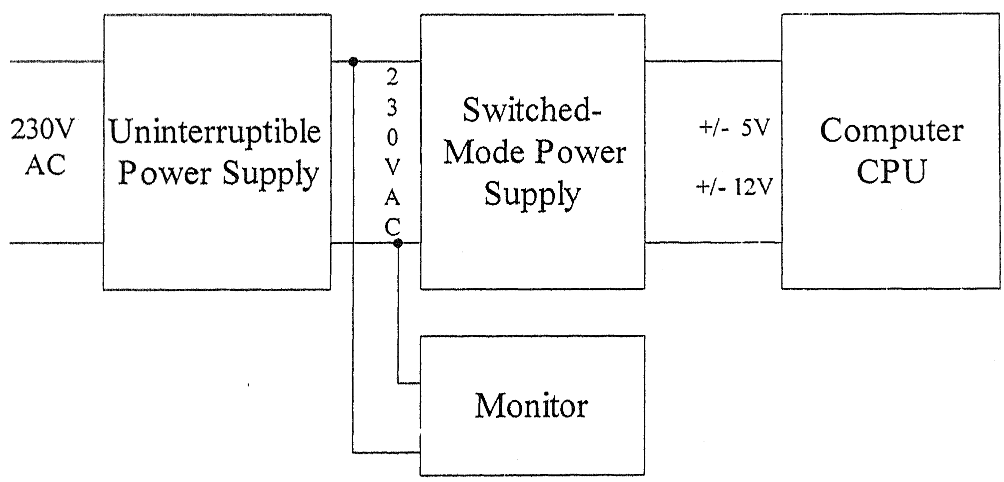

Fig 1.1 Conventional SMPS and UPS combination to power PC.

To protect computers from power line failure, an external uninterruptible power supply (UPS) is often added, which precedes the switched-mode power supply (SMPS)

of computer as shown in Fig 1.1. This modular approach is systematic and relatively easy, but it is not optimized. The UPS is often bulky due to the use of line frequency inverter. Besides, the system conversion efficiency from ac input to dc output of computer power supply will be low due to multiple power conversion stages.

The mains AC supply is first converted into DC and the batteries inside the UPS are charged. The stored energy from batteries (i.e. DC voltage) is converted into AC by an inverter which operates at mains frequency to feed the SMPS inside the CPU cabinet. The main function of SMPS inside the CPU cabinet of personal computer is to provide the regulated DC voltages needed for the personal computer. In switched-mode power supply the AC voltage is rectified, filtered, and supplied to the electronic chopper, which operates at a frequency above the audible range to prevent acoustic noise. The chopped DC voltage is again converted into various voltage levels by a suitable multi-winding transformer. These high frequency voltages then filtered to get DC which is supplied to PC. This process, though widely used, is very inefficient, needs lots of hardware, and is costly. The redundant voltage conversions and inversions bring down efficiency and make the circuit bulky. To solve all these problems in an elegant way, a power supply has been developed which has high efficiency, low cost and compact for supplying power to PCs replacing SMPS and UPS. The system developed gives stable ±12V, ±5V, +230V needed for driving both CPU and monitor.

1.2 Proposed System:

1.2.1 Overall circuit block diagram:

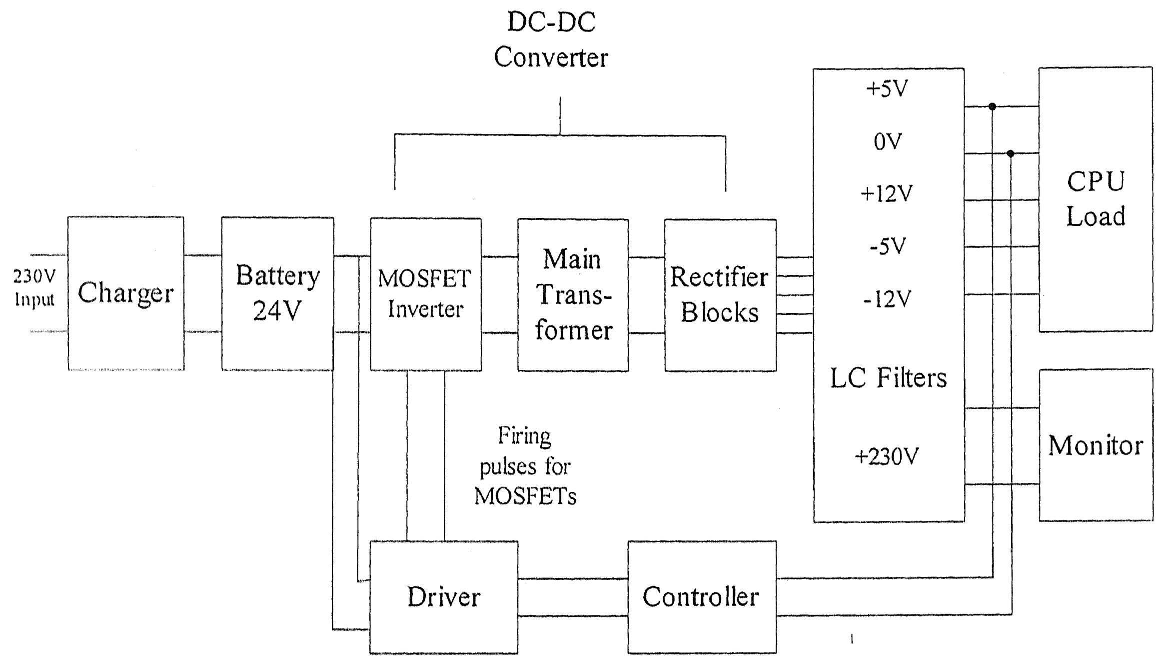

Fig 1.2 Uninterruptible switched-mode power supply

1.2.2 Benefits:

The benefits of the proposed system can be enumerated as follows.

- The power supply has high efficiency compared to UPS-SMPS combination.
- The overall power supply is compact.
- The power supply has low cost.
- The weight of overall power supply is lower compared to conventional UPS-SMPS combination.

1.2.3 Brief Description:

As shown in Fig 1.2 above, the developed power supply has minimum number of components with no redundant conversions. The power supply is compact, which is slightly larger than a conventional switching power supply but much smaller than an UPS, due to the removal of redundant low frequency inverter and use of high switching frequency. First, the AC from the mains is converted to DC using charger to energize batteries. All the power needed for the CPU and monitor is drawn from these batteries all the time. The DC voltage of the batteries is converted into high frequency AC using an inverter. The Inverter is developed using full bridge topology. The control signals are generated by using pulse width modulation (PWM) feedback controller IC UC3525AN. The gating logic signals generated by control circuit are transformed as power signals required for firing MOSFET by driver circuit. The independent power supplies required to power the driver circuit are achieved by deploying a flyback converter. The firing signal required to trigger MOSFET in flyback converter is obtained by using a 555 timer. The high frequency AC voltage from inverter is fed to main transformer which has 5 secondary windings as per the requirements of PC. The AC Voltages available at transformer's secondary winding is at very high frequency which is rectified and are filtered by using low pass filters to get ripple free DC as need by the different components of PC.

To control the output voltage, closed loop voltage control is used. In this type of control, the output voltage is sensed in order to maintain its required voltage level. The output of error amplifier goes into a comparator that compares the error voltage with the ramp created by the oscillator section of PWM in IC UC3525AN. This Comparator converts the error voltage into a pulse width modulated waveform in order to drive the

power switches in a pulse width modulated on/off fashion. To make power supply stable, suitable controller is used. The +5V voltage output is the most important, and should be the most stable. To ensure this, any changes in this voltage are sensed and accordingly the duty cycle of the inverter is adjusted.

As all redundant power conversion stages are eliminated by integrating the external UPS into computer switching power supply and also the circuit is designed with minimum losses, the proposed system has efficiency higher than the conventional UPS and SMPS combination. By eliminating redundant inverter, converter and using higher frequency, it is possible to keep the power supply's size compact enough to be able to fit inside the CPU cabinet itself. Extra batteries can be plugged from outside for extended back up time.

1.3 Organization of the Thesis:

The thesis is organized into six chapters.

Chapter 1 describes the introduction, problem definition and the proposed solution.

Chapter 2 describes with power supplies for personal computer.

Chapter 3 outlines the high frequency inverter used to convert the DC to high frequency AC, and its control circuit.

Chapter 4 highlights the design and fabrication of the high frequency transformer used to get multiple voltages needed for various components of computer.

Chapter 5 describes with rectifier and filter circuits used to filter out ripples in the output of power supply and closed loop operation.

Chapter 6 gives the experimental results with conclusion and future scope of work.

Chapter 2

Power Supplies for Personal Computer

2.1 Switched-Mode Power Supply (SMPS):

Conventional series-regulated linear power supplies maintain a constant voltage by varying their effective resistance to cope with input voltage changes or load current demand changes. The linear regulator can, therefore, tend to be very inefficient. Due to high efficiency and high power density as well as reduced costs, switched-mode power supplies(SMPS) are now becoming more popular compared to the linear power supplies.A switched-mode power supply is one that provides the required voltage/current through low loss components such as capacitors, inductors, and transformers and the use of high frequency switching devices to reduce the size of the magnetics.The switching devices dissipate very little power and power conversion can be accomplished with minimal power loss, which results in high efficiency. SMPS is a power source which utilizes the energy stored during one portion of its operating cycle to supply power during the entire duration of its operating cycle. SMPS operates on the chopper principle and is used to get regulated dc output voltages. SMPS can be used to step-down a supply voltage, just as linear supplies do. Unlike a linear regulator, however, an SMPS can also provide a step-up function and an inverted output function. It uses MOSFET as switching element (as MOSFET has low switching loss compared to transistor at high switching frequency) for the output power below a couple of kilowatts.

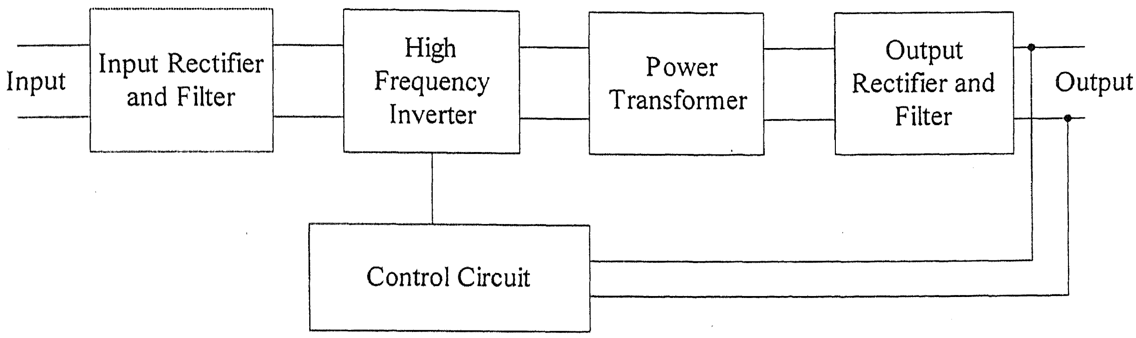

Fig 2.1 Block diagram of SMPS

The block diagram of the SMPS is shown in fig 2.1. The AC voltage is rectified, smoothed and supplied to the electronic chopper, which operates at a frequency above the audible range to prevent acoustic noise. The filter shown on the left of the diagram is necessary to prevent the supply from causing interference from the mains. It can also help to protect the SMPS circuitry from voltage spikes (or power surges) in the mains supply. The unregulated dc is fed directly to the central block of the supply, the high frequency power switching section. Fast switching power semiconductor devices such as MOSFETs are driven on and off, and switch the input voltage across the primary of the ferrite core power transformer. Thus, the unregulated DC voltage is converted into high frequency AC to get various voltage outputs. The drive pulses are normally fixed frequency (20 to 200 kHz) with variable duty cycle. Hence, a voltage pulse train of suitable magnitude and duty ratio appears on the transformer secondaries. This voltage pulse train is appropriately rectified, and then smoothed by the output filter, which is either a capacitor or capacitor / inductor arrangement, depending upon the topology used. This transfer of power has to be carried out with the lowest possible loss, to result in higher efficiency. Thus, optimum design of the passive and magnetic components, and

selection of the correct power semiconductor is critical. The high frequency AC voltages are then filtered to get DC which is supplied to PC.

2.1.1 Applications of SMPS:

The application of switched-mode power supplies include

- SMPS are used to provide regulated voltages for CPU of computer
- Television
- display panels
- Electric vehicles
- Power supply in space vehicles etc.

2.1.2 Advantages of SMPS over Linear Regulators;

- It has high efficiency due to the use of lossless components.
- The size of SMPS is small.
- The weight of SMPS is lower compared to linear regulators.
- High power density (approximately 30 to 300W/Kg)
- Multiple outputs are possible
- Less sensitive to input voltage variations
- Can be used for both step up and step down converters.

2.1.3 Disadvantages:

- The design of SMPS is complex.
- The voltages have high ripples which have to be filtered.
- There is possibility of EMI.
- Overall cost is high.

2.1.4 Classification of SMPS:

Non Isolated SMPS (no transformer between source and load)

- Buck converter ($V_O < V_{in}$)
- Boost converter ($V_O > V_{in}$)
- Buck Boost converter ($V_O < V_{in}$ or $V_O > V_{in}$)
- Cuk converter

Isolated SMPS (transformer between source and load)

- Flyback converter
- Forward converter
- Push pull converter
- Half Bridge converter
- Full Bridge converter

2.1.5 Comparison of SMPS:

Topology	Power Range (Watts)	Vin (DC) Range	Input/Output Isolation	Efficiency (%)	Relative cost
Buck	0-1000	5-1000 V	No	75	1.0
Boost	0-150	5-600 V	No	78	1.0
Buck- Boost	0-150	5-600 V	No	78	1.0
Half-Forward	0-250	5-500 V	Yes	75	1.4
Flyback	0-150	5-600 V	Yes	78	1.2
Push-Pull	100-1000	50-1000V	Yes	72	2.0
Half- Bridge	100-500	50-1000V	Yes	72	2.2
Full-Bridge	400-2000	50-1000V	Yes	69	2.5

Table 2.2 Comparison of PWM switching regulator topologies

2.2 Uninterruptible Power Supply:

For supplying very critical loads such as computers, medical equipment etc., it is necessary to use uninterruptible power supply (UPS). UPS provides protection against power outages as well as voltage regulation during power line over voltage and under voltage conditions. They are also excellent in terms of suppressing incoming line transient and harmonic disturbances. The traditional way to protect computers against power failure is to add an uninterruptible power supply preceding the input of the switched-mode power supply. The UPS is often bulky due to the use of line frequency inverter. UPS is used as supply backup in the case of power failures. In addition to filtering, enhancing or modifying the utility power, special circuitry and batteries are used to prevent the load from losing power during a disruption (blackout) or voltage sag (brownout). These units are called by different names depending on their exact design, but all fit into the general category of backup power.

2.2.1 On-Line UPS Operation:

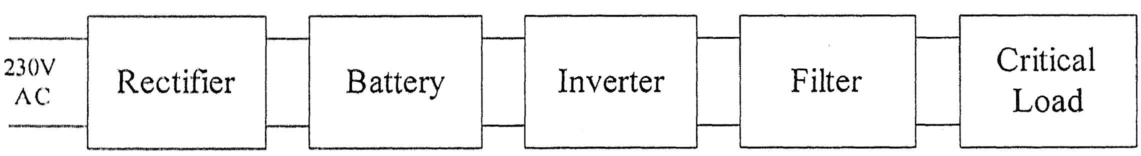

Fig 2.3 Block Diagram of On-Line UPS

In an online UPS the AC is first converted into DC and stored in a battery. The load is continuously supplied from the battery. The DC voltage from the battery is

converted to AC by means of an inverter. The AC voltage from the inverter is smoothened by filter circuit and is supplied to the load.

2.2.2 Parts of the Uninterruptible Power Supply:

Rectifier

The main function of rectifier circuit is to supply power to charge batteries. Rectifier converts the mains AC supply to DC supply needed to charge batteries. The rectifier may be a phase controlled rectifier or a diode rectifier bridge in cascade with a step down dc-dc converter.

Battery

Other than the core circuitry of the UPS, the other main component is the battery, which holds the energy that is used by the UPS to run the equipment. It is the size of the battery that dictates the size of the UPS unit as a whole. The size of the battery is also proportional to the amount of energy that is stored in the UPS, and therefore, the length of time that the UPS will run for a given load depends on the battery voltage and ampere-hour rating.

Inverter

The main function of inverter is to convert input DC voltage to output AC voltage. Inverter must allow almost instantaneous control over its output ac waveform. The filtered output of the inverter is normally specified to contain very little harmonic distortion, even though most loads are highly nonlinear and, hence, inject larger harmonic currents into the UPS. It is important to minimize the harmonic content of the

inverter output. This decreases the filter size, which improves the dynamic response of the UPS as load changes.

2.3 Personal Computer -Power Requirements:

The internal power supply is responsible for converting the standard available power into the form that can be used by computer. The power supply is responsible for powering every device in the computer. Personal computers, like most electronic devices, run on direct current (DC). The function of computer's power supply is to convert the alternating current (AC) to the direct current (DC) with regulated output voltages. Internally, personal computers require ± 5V and ±12V for CPU and 230V DC for the monitor. The voltages have to be well regulated as the internal components in a personal computer are highly sensitive to voltage variation.

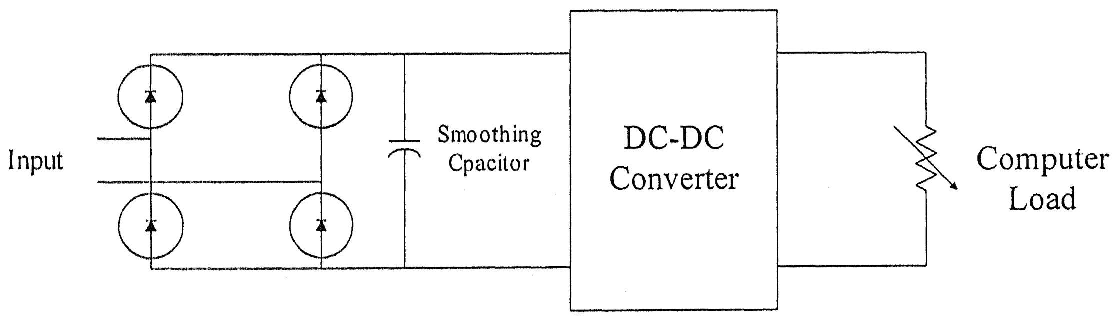

Fig 2.4 Basic Structure of computer power supply.

2.3.1 Role of Power Supply

The power supply plays an important role in the following areas of PC:

Stability: A high quality power supply with sufficient capacity to meet the demands of computer will provide years of stable power for PC. A poor quality or overloaded power supply will cause all sorts of glitches and voltage variations that are detrimental for the system. For example, power supplies can cause system crashes, can make hard disks develop bad sectors, or cause software bugs to appear, problems which can be very difficult to trace back to the power supply.

Cooling: The power supply contains the main fan that controls the flow of air through the PC case. This fan is a major component of PC's cooling system.

Energy Efficiency: Newer PC power supplies work with computer's components and software to reduce the amount of power they consume when idle. This can lead to significant savings over older systems.

Expandability: The capacity of power supply is one factor that will determine the ability to add new drives to computer system, or upgrade to a more powerful motherboard or processor. For example, that a high-speed Athlon CPU and motherboard consume far more power than a similar Pentium based system, and the power supply needs to be able to provide this extra power. If power supply is built that barely meets the needs, it must be replaced when the system is upgraded.

2.3.2 Dependency of Computer Downtime and Computer Expense:

Problems for Computer Down:

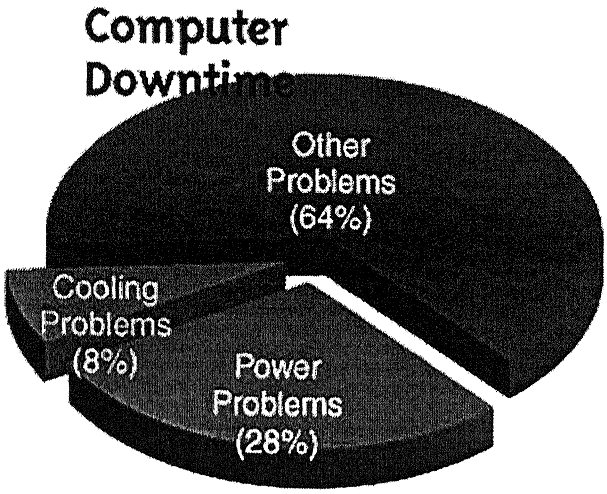

Fig 2.5 Problems for computer down

Computer expense:

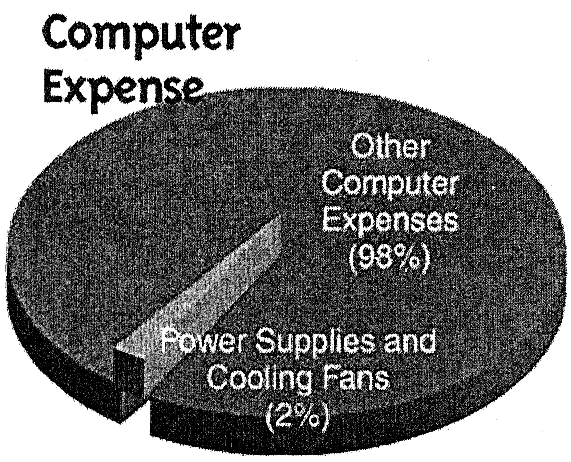

Fig 2.6 Computer expense

These pie charts shows the importance of computer power supply compared to other components of computer. Despite

their low cost compared to other components, power and cooling are responsible for a large percentage of overall system problems.

2.3.3 Standard Output Voltages of SMPS used in CPU:

PCs use several different voltages to power their various components. The core voltages have mostly remained unchanged over the 20 year history of the PC, though a couple of the less used voltages have essentially been dropped, and an important new one has been added. The power supply provides each of these voltages, in varying amounts depending on the model, directly from its circuitry. Most of the power provided by the power supply is in the form of positive voltages, but some is in the form of negative voltages.

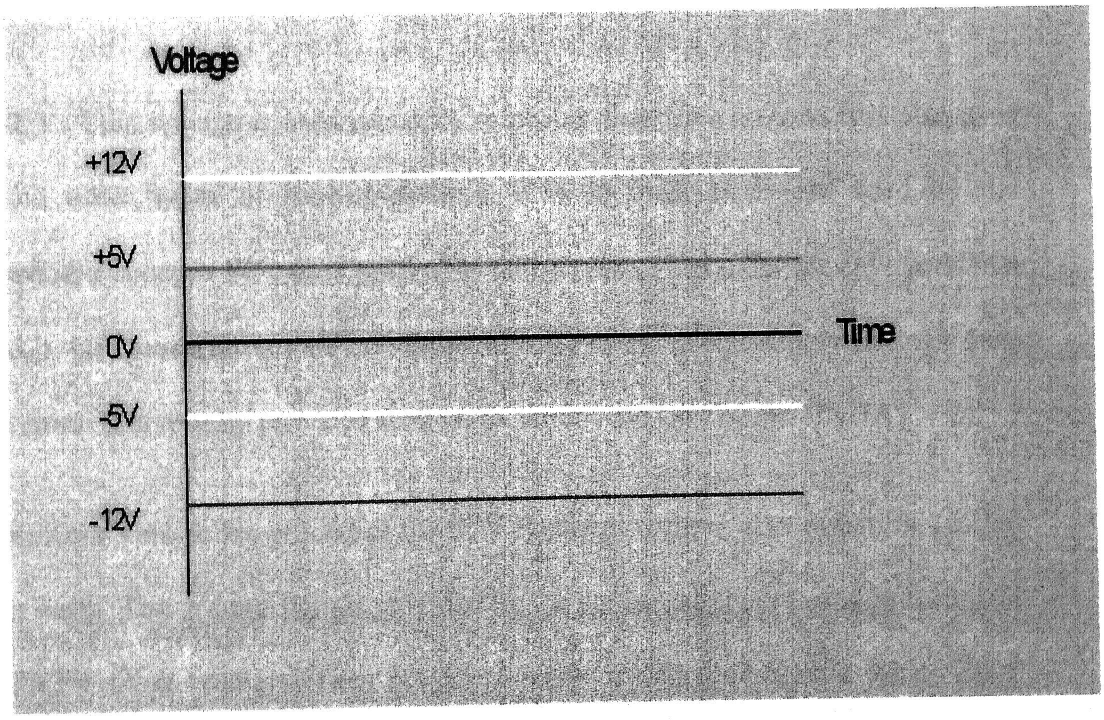

Fig 2.7 Standard output voltages of SMPS used in CPU

The fig 2.7 shows various voltages provided by a switched-mode power supply used in CPU of computer. The colour of each line corresponds to the colour normally given to wires carrying that voltage in the power supply's motherboard connectors. The black zero voltage line represents system's ground, which is the reference point.

The amount of current provided at each voltage level is important because of its impact on determining the supply's ability to provide sufficient power for computer system.

The details on the various voltages provided by computer power supplies:

+5 V: Which was used to provide power to the CPU, memory, and everything else on the motherboard. On newer systems, many of the components, especially the CPU, have migrated to the lower +3.3 V, but the motherboard and many of its components still use +5 V. The current rating of this supply is the maximum(generally 20A).

+12 V: This voltage is used primarily to power disk drive motors. It is also used by fans and other types of cooling devices. It is in most cases not used by the motherboard in a modern PC but is passed on to the system bus slots for any cards that might need it. Of course, drives are connected directly to the power supply through their own connectors. It is usually provided with large current capacity (generally 7A).

0 V: Zero volts is the ground of the PC's electrical system, also sometimes called common or earth. The ground signals provided by the power supply are used to complete circuits with the other voltages. They provide a plane of reference against which other voltages are measured.

-12 V: This voltage is used on some types of serial port circuits, whose amplifier circuits require both -12V and +12V. Most power supplies provide it for compatibility with older hardware, but usually with a current limit of less than 1 A.

-5 V: -5 V was used in PCs for floppy controllers and other circuits used by ISA bus cards. It is usually provided, with small current rating (generally less than 1A), for compatibility with older hardware.

2.3.4 Monitor:

Monitor is the component that displays the visual output from the computer as generated by the video card. It is different from most of the other components of the PC due to its passive nature. It is not responsible for doing any real computing, but rather for showing the results of computing. Monitors are important not because of their impact on performance, but rather their impact on the usability of the PC. A poor quality monitor can hamper the use of an otherwise very good PC, because a monitor that is hard to look at can make the PC hard to use.

Monitor plays a significant role in the following important aspects of your computer system:

- **Comfort and Ergonomics:** Working with the video card, monitor determines the quality of the image that appears when the PC is in use. This has an important impact on

how comfortable the PC is to use. Poor quality monitors lead directly to eye strain and other problems, and can ruin the computing experience.

- **Software and Video Mode Support**. A video card that can drive high resolutions in true color at high refresh rates is useless without a monitor that can handle them as well.

- **Upgradeability:** Since most monitors are interchangeable with each other and can be used on any similar PC, they are naturals to carry over to a new machine or to use after upgrading.

Subsystems of Monitor:

A computer or video monitor includes the following functional blocks:

- Low voltage power supply
- Horizontal deflection
- Vertical deflection
- CRT high voltage flyback power supply:
- Video amplifiers
- Video drivers (RGB)
- Sync processor
- System control

Power needed for Monitor: The computer monitor remains the largest energy consumer for PC components. When a 17" monitor is on, it consumes up to 60 watts. Screen savers don't save energy. In fact, standby energy use of a personal computer with a screen saver almost doubles.

2.4 Conclusion:

Personal computer needs a suitable regulated DC power for its operation. Traditionally SMPS is used to power the CPU. SMPS uses high frequency switching, that results in low weight of magnetics and overall compact design. UPS is used for preventing supply voltage variations and interruptions. However, the UPS-SMPS combination leads to multiple power conversion stages resulting in low efficiency. Further, the overall size of UPS-SMPS becomes large. These disadvantages have to be overcome to have efficient and compact uninterruptible power supply for the PC.

Chapter 3

Inverter and Control Circuit

3.1 Control Circuit:

The output dc voltage of switched mode power supply is controlled by adjusting the duty cycle by

1) Frequency modulation

2) Pulse width modulation

In frequency modulation, the switch is cycled at 50% duty cycle, the frequency is varied untill the output voltage comes into regulation. In pulse width modulation, the switching frequency is kept constant and the duty cycle is varied with the load.

3.1.1 Pulse Width Modulation

The pulse width modulation, or PWM, control technique maintains a constant switching frequency and varies the ratio of charge cycle to discharge cycle as the load varies. This technique affords high efficiency over a wide load range. As the switching frequency is fixed, the noise spectrum is relatively narrow, allowing simple low pass filter techniques to reduce the peak to peak voltage ripple. With pulse width modulation control, the regulation of output voltage is achieved by varying the duty cycle of the switch, keeping the frequency of operation constant. Duty cycle refers to the ratio of the period for which the power semiconductor is kept on to the cycle period. Usually control by pulse width modulation is the preferred method since constant frequency operation leads to optimization of LC filter and the ripple content in output voltage can be controlled within the set limits. The integrated PWM control IC UC3525AN is used to generate the control signals required to drive the MOSFETs used in inverter.

3.1.2 Types of Pulse Width Modulation

Pulse width modulation comes in a couple of different flavors. In voltage mode pulse width modulation, the divided down output voltage is fed to an error amplifier whose output is the difference between a reference voltage and the divided down output voltage. This error voltage sets the threshold of a comparator whose other input is connected to a ramp generator. The output of the comparator drives the main switch. On cycle by cycle basis, the greater the error voltage, the higher the comparator threshold on the comparator, and the longer the switch is held on. As the switch is held on longer, the peak current in the inductor is allowed to climb higher, storing more energy to serve the load and maintain regulation. Current mode pulse width modulation works in a similar fashion but with a key difference. As with the voltage mode PWM, the divided down output voltage is fed to an error amplifier whose output is the difference between the fedback output voltage and a voltage reference. However, instead of setting the threshold on a ramp generator, this scheme employs a current sense resistor to sense the inductor current and flip flop to control the switch. With each cycle, the switch is turned on by a pulse oscillator and the current in the inductor ramps up to the threshold set by the error voltage. This control scheme tends to be a bit easier to stabilize than the voltage mode pulse width modulation.

3.1.3 UC3525AN Block Diagram:

The block diagram of UC3525AN is shown in figure.

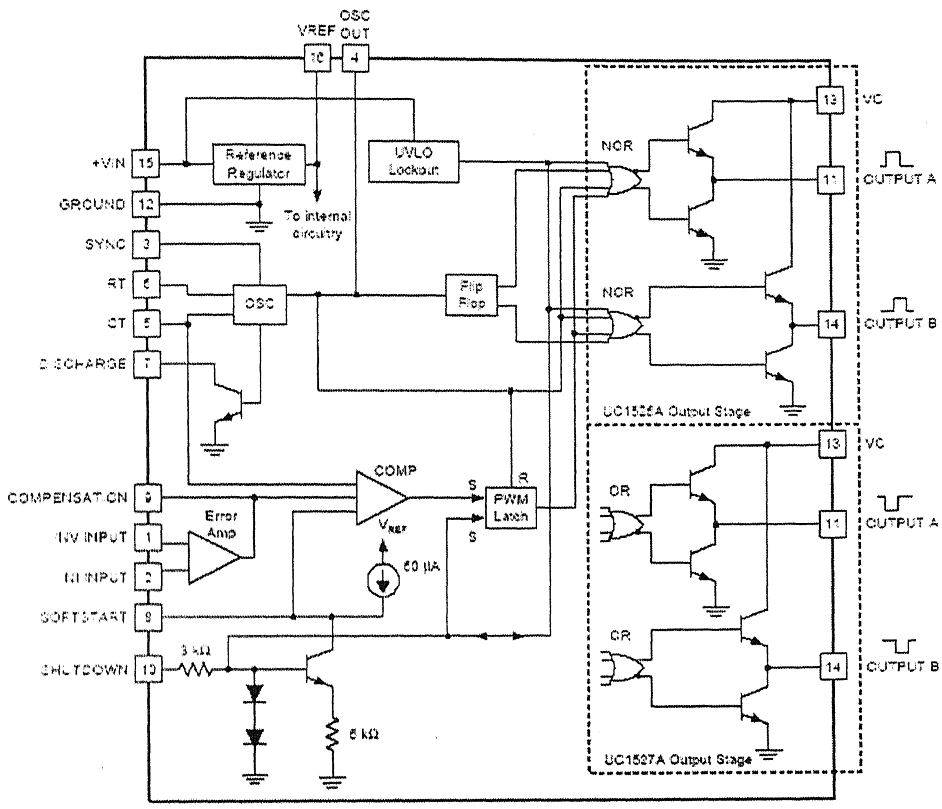

Fig 3.1 Block diagram of UC3525AN

3.1.4 Main Features of the IC UC3525AN:

- 8 to 35 V Operation
- 5.1 V Reference Trimmed to ±1%
- 100 Hz to 500 kHz Oscillator Range
- Separate Oscillator Sync Terminal
- Adjustable Dead time Control
- Internal Soft-Start
- Pulse-by-Pulse Shutdown
- Input Under voltage Lockout with Hysteresis
- Latching PWM to Prevent Multiple Pulses
- Dual Source/Sink Output Drivers

3.1.5 The Functional Blocks of the IC UC3525AN:

UC3525AN is a pulse width modulation feedback controller. It uses negative feedback to force the voltage at the inverting input of the error amplifier to be equal to the voltage at the non-inverting input of the error amplifier.

1. An internal linear saw tooth oscillator as shown in fig 3.2 is frequency programmable by a resistor R_T and C_T. The oscillator frequency is determined by

$$f = \frac{1}{C_T\,(0.7R_T + 3R_D)}$$

R_T = Timing resistor in Ω, C_T = Timing capacitor in μF, R_D = Dead time adjustment resistor in Ω.

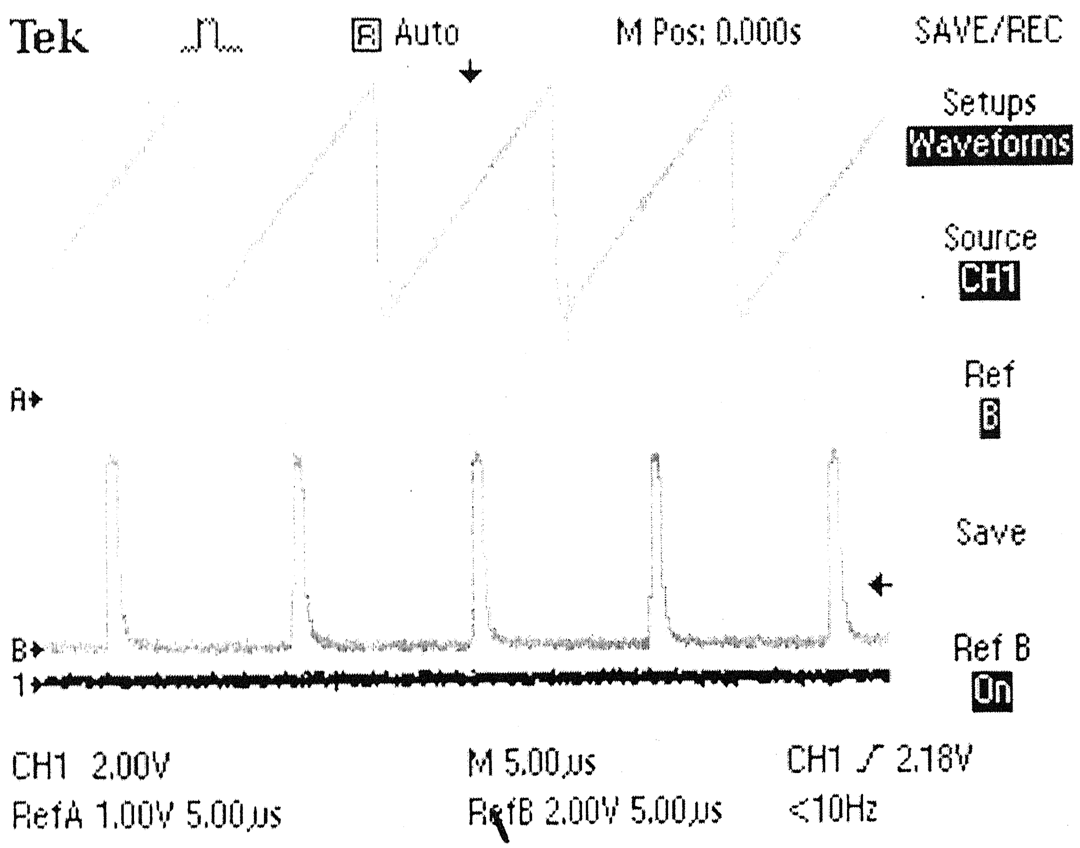

Fig 3.2 Ramp wave and clock generated by oscillator

The ramp voltage shown in Fig 3.2 swings approximately 2.5 V to change the comparator output from 0 to 1, by comparing it with the error amplifier output.

2. Output drivers that provide enough drive current for low and medium power applications.
3. A voltage reference that provides the overall power supply ideal reference to which the output voltages are compared.
4. A voltage error amplifier that performs a high gain voltage comparison between the output voltages and stable reference.
5. An error voltage to pulse width converter that sets the duty cycle output in response to the level of the error voltage from the voltage error amplifier.
6. A soft-start circuit that starts the power supply in a smooth fashion, reducing the inrush current and provides gradual rise in the output voltages.
7. Dead time control that fixes the maximum pulse width the control IC can generate, thus preventing the occurrence of simultaneous conduction of two power switches or 100 percent duty cycles.
8. Under voltage lockout to prevent the supply from starting when there is insufficient voltage with the control circuit for driving the power switches into saturation.

3.1.6 Pin Diagram:

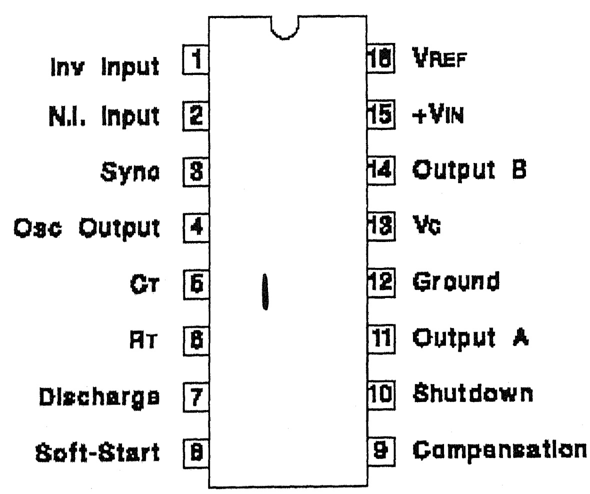

Fig. 3.3 Pin diagram of UC3525AN

3.1.7 Circuit Diagram of Control Circuit:

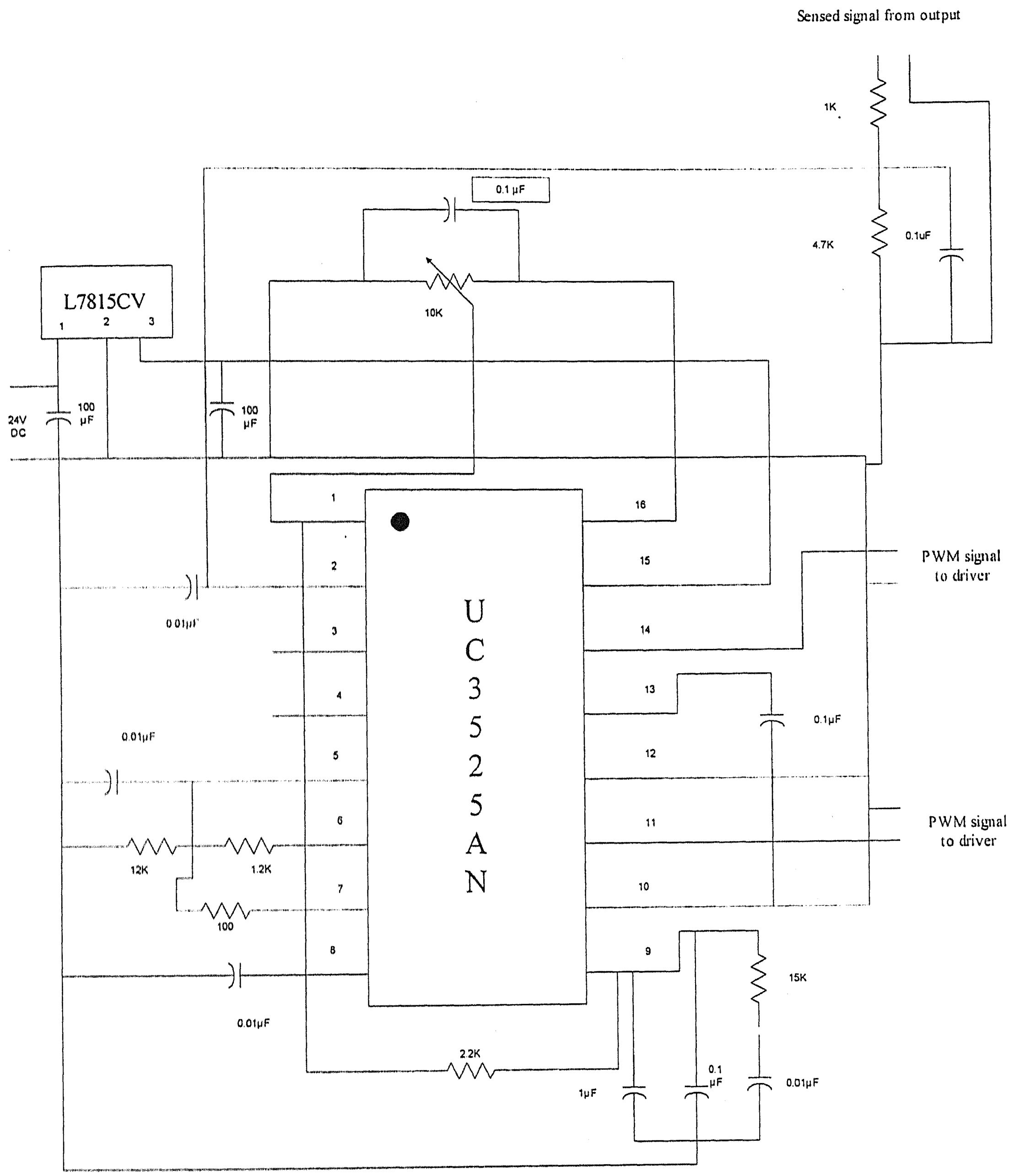

Fig 3.4 Controller circuit diagram

3.1.8 Output Waveform of Control Circuit:

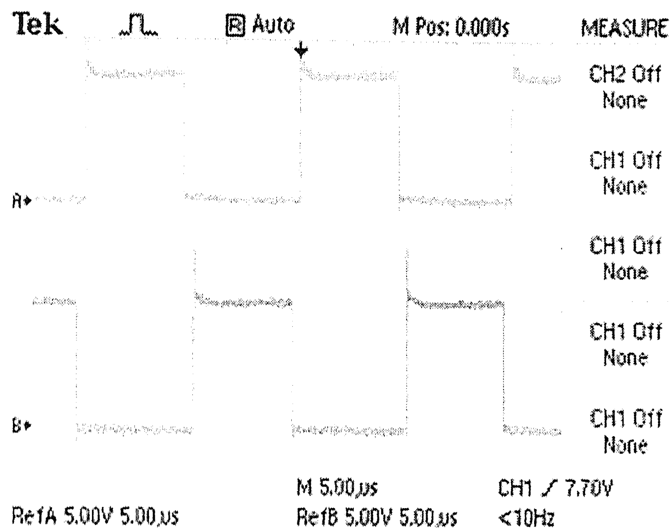

Fig 3.5 Output waveform of control circuit

3.2 Driver Circuit:

The gating signals generated by the control circuit are logic signals, where as power signals are needed to drive the MOSFETs used in inverter. The main function of driver circuit is to convert the logic signals generated by control circuit to power signals required to drive the MOSFETs in inverter and also provides the electrical isolation between control circuit and power circuit.

The requirements of gate drivers for MOSFETs are:

- A fast rising gate current for fast turn on.
- Hard turn on drive to reduce turn on loss.
- Adequate gate voltage for low conduction loss.
- Negative gate drive for fast turn off.
- Negative gate bias during off time for good noise immunity.
- Insensitive operating point.

- Electrical Isolation between control input and drive input.
- Overriding protection while switching a faulty device.

3.2.1 Block Diagram:

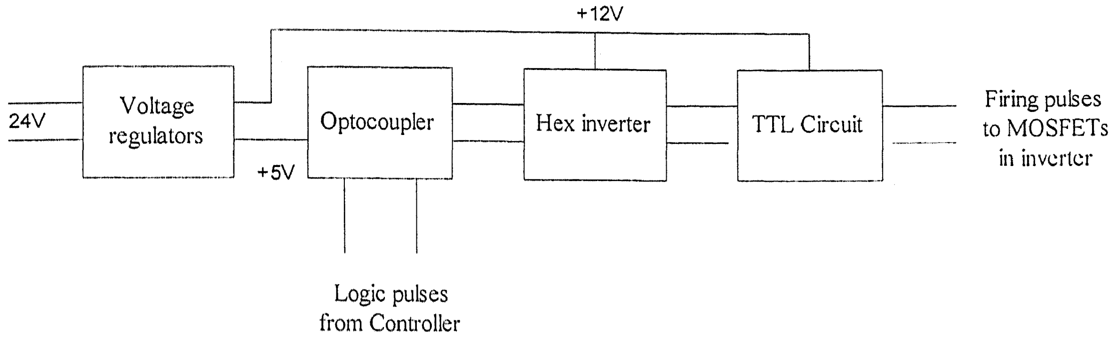

Fig 3.6 Block diagram of driver

3.2.2 Isolated Power Supply for Driver Circuit:

The driver circuit needs at least 3 isolated power supplies of 15 volts minimum each. For high power applications, an active gate drive circuit is employed directly at the MOSFET gate, and both control signal and power are transmitted across the isolation barrier. The power is either provided by a small DC-DC converter, or more commonly by a flyback converter with multiple isolated outputs. The inter-winding capacitance of these transformers should be kept low to avoid the large common mode currents.

Flyback Converter:

The function of flywheel used in electric drives is for load equalization. The flyback converter operates similar to flywheel, it provides electrical isolation between input and output. When switch is on, the energy is stored in the transformer and when the switch is off, the energy stored in transformer is transferred to load. During on period the capacitor supplies the energy required by the load. Flyback converter requires minimum number of components compared to other types of converters. To increase the stored energy, a gapped core is often used. RM10 core is used as core for flyback transformer.

Circuit Diagram and Operation:

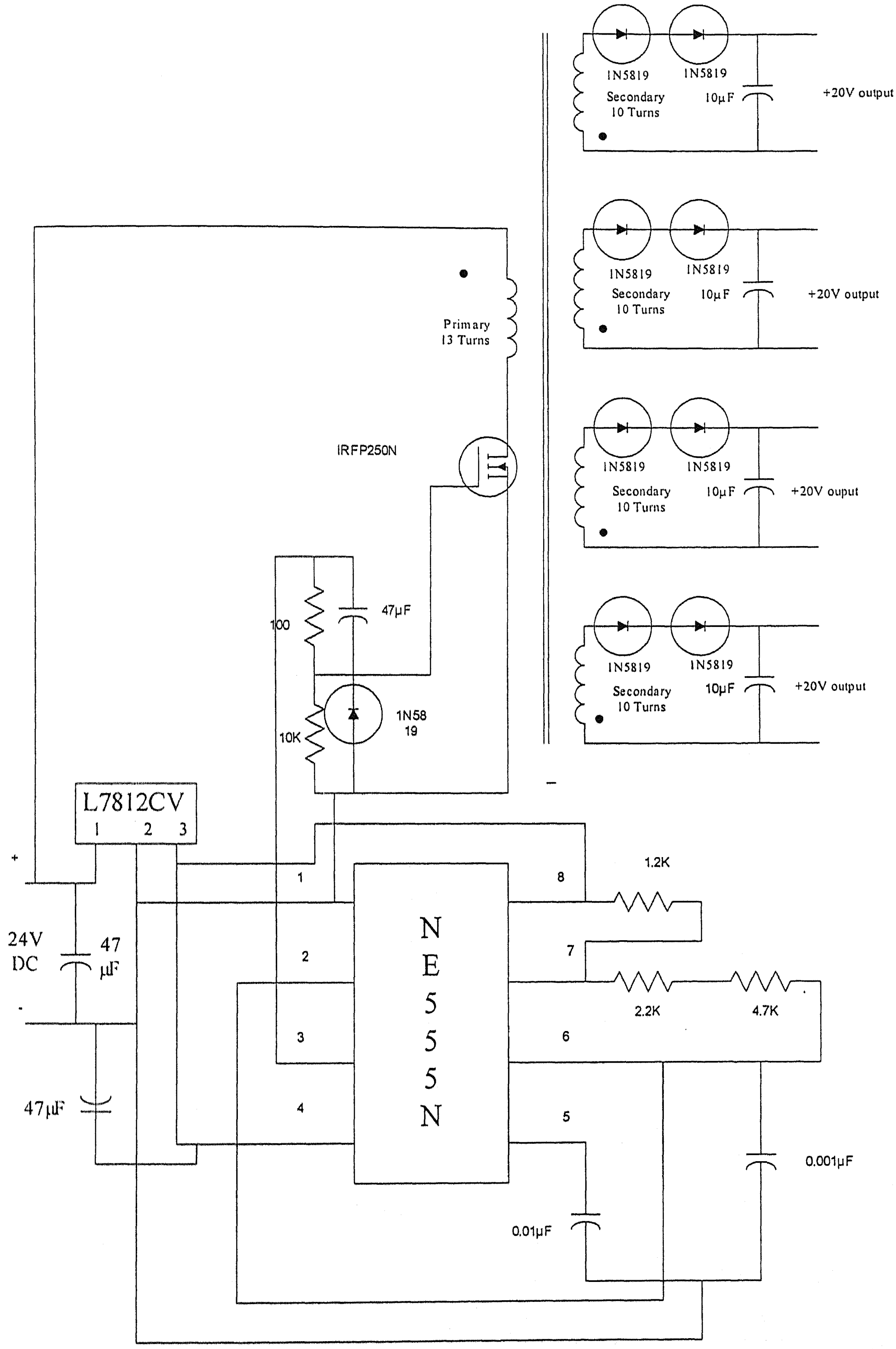

Fig 3.7 Multi-output flyback converter

The polarity of the windings is such that the output diode blocks during the switch on time. When the switch turns off, the secondary voltage reverses, maintaining a constant flux in the core and forcing secondary current to flow through the diode to the output load. The magnitude of the peak secondary current is the peak primary current reached at switch turn off reflected through the turns ratio, thus maintaining a constant ampere-turn balance. The fact that all of the output power of the flyback has to be stored in the core as $\frac{1}{2}LI^2$, means that the core size and cost will be much greater than in the other topologies, where only the core excitation or magnetization energy, which is normally small, is stored. This, in addition to the initial poor unipolar core utilization, means that the transformer bulk is one of the major drawbacks of the flyback converter. In order to obtain sufficiently high stored energy, the flyback primary inductance has to be significantly lower than required for a true transformer, since high peak currents are needed. This is normally achieved by gapping the core. The gap reduces the inductance, and most of the high peak energy is then stored in the gap, thus avoiding transformer saturation. The action of the flyback means that the secondary inductance is in series with the output diode when current is delivered to the load; i.e. driven from a current source. This means that no filter inductor is needed in the output circuit. Hence, each output requires only one diode and output filter capacitor. This means the flyback is the ideal choice for generating low cost, multiple output supplies. The cross regulation obtained using multiple outputs is also very good (load changes on one output have little effect on the others) because of the absence of the output choke, which degrades the dynamic performance. The flyback is also ideally suited for generating high voltage outputs.

The output capacitor is only supplied during the switch off time. This means that the capacitor has to smooth a pulsating output current which has higher peak values than the continuous output current that would be produced in a forward converter, for example. In order to achieve low output ripple, very large output capacitors are needed, with very low equivalent series resistance. At the same frequency, an LC filter is approximately 8 times more effective at ripple reduction than a capacitor alone. Hence, flyback converter has inherently much higher output ripples than other topologies. Due to higher peak currents, large capacitors and transformers, limits the flyback converter to low output power applications in the range of 20 to 200W. 555 timer is operated in astable mode to get the firing pulse for firing power MOSFET. Diodes used are IN5819, which are schottky diodes, which are characterized by low voltage drop and very small recovery time.

Design:

Input voltage, V_{in}= 24 V

Output voltage, V_o = 20 V

Switching frequency, f_s =80 kHz

Time period , $T_s=1/f_s=12.5\ \mu S$.

Duty cycle , D=0.54

Flux Density, B_{max} = 0.1 Tesla = 1000 Gauss

Average secondary current, I_{2avg} = 50 mA

Peak secondary current, $I_{2p} = 2*I_{2avg}/(1-D)$

$= 0.2174$ A

Output power, Pout=4 Watt

Efficiency, η=80%=0.08

Energy stored in primary , $E = \frac{1}{2} L I^2$

Power, P=E/T

primary current, $I_p = V_{in} T_{on}/L_p$

Pin=4/0.8=5

Pin= V_{in} * V_{in} *D*D*T/(2* L_p)

by substituting Pin=10, V_{in} = 24, D=0.54, T=12.5μS

Primary inductance, L_p = 209.952 μH

Then by substituting L_p in I_p equation and solving for I_p

Primary current, I_{1p}=0.7716 Amp.

for RM10 core, Ae =0.63 sq.cm

length of air gap, Ig=0.4*Lp*Ip*I_1p*10^8/Ae*B_{max}*B_{max}=0.2493 mm

Number of primary turns

Taking Np=13

Number of secondary Turns

Ns=N_p (V_{out}+V_{mosfet})(1-D)/(V_{in} *D)=9.6$\approx$9

Calculation of wire gauge for primary:

Taking J(current density of copper)$\approx$3 A/mm^2,

Cross section area of the primary wire a_{wp}=I_{1p} / J =0.7716/3=0.2752 mm^2

Hence, the diameter of the primary winding wire= 0.5722 mm.

SWG wire has to be used = SWG23

Calculation of wire gauge for secondary:

Taking J (current density of copper) ≈ 3 A/mm^2,

Cross section area of the secondary winding $a_{ws} = I_{2p} / J = 0.2174/3 = 0.07246$ mm^2

Hence, the diameter of the secondary winding = 0.3037 mm.

SWG wire has to be used = SWG30

Winding	Voltage	No. of Turn	Diameter	SWG wire used
Primary	+24V	13	0.5722 mm	SWG 23
Secondary	+20V	9	0.3037 mm	SWG 30

Table 3.8 Winding specifications

Output Waveform of Flyback Converter:

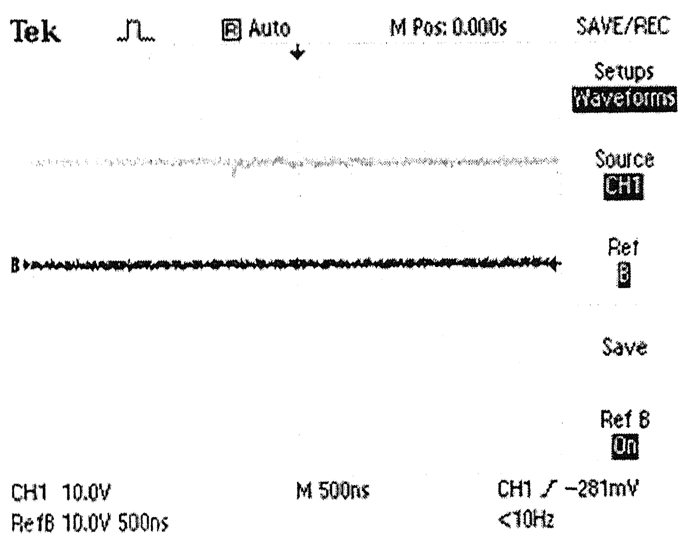

Fig 3.9 Output waveform of flyback converter

3.2.3 Optocoupler:

Main function of optocoupler is to provide electrical isolation between control circuit and power circuit. 6N137 is used as optocoupler. Optocoupler provides electrical isolation between input signal and output signal. When the control pulse is applied to LED, it emits light and turns on the photo transistor. The current output from the photo transistor acts as the base current for the transistor.

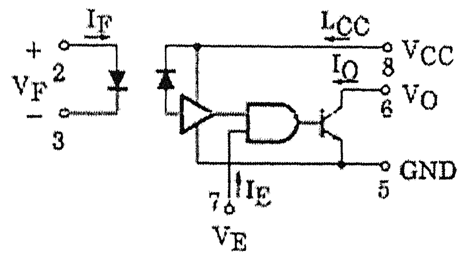

Fig 3.10 Circuit diagram of optocoupler

Pin Diagram:

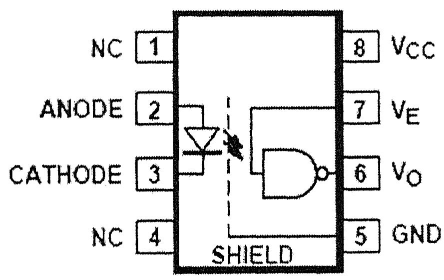

Fig 3.11 Pin diagram of optocoupler 6N137

3.2.4 Hex Inverter:

Optocoupler inverts the signal from controller. The main function of inverter is to convert the output signal from optocoupler to the signal similar to the signal from controller. The inverter is also used as amplifier to amplify the signal from optocoupler.

IC used is MM74C901N. This IC employs complementary MOS to achieve wide supply operating range (3 to 15V), low power consumption, and high noise immunity

Pin Diagram of IC MM74C901N:

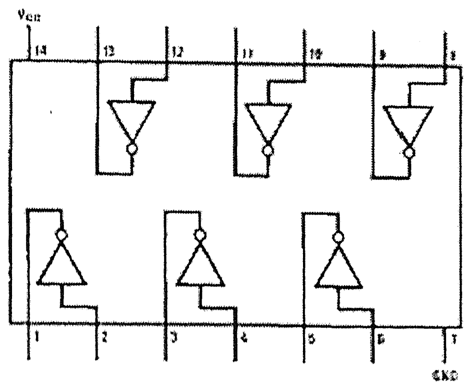

Fig 3.12 Pin diagram of MM74C901N

3.2.5 TTL Circuit:

Power MOSFETs need large current spikes (of few amperes) to fire them. So, TTL circuit is used, so that it can supply the current spikes needed to fire the power MOSFETs.

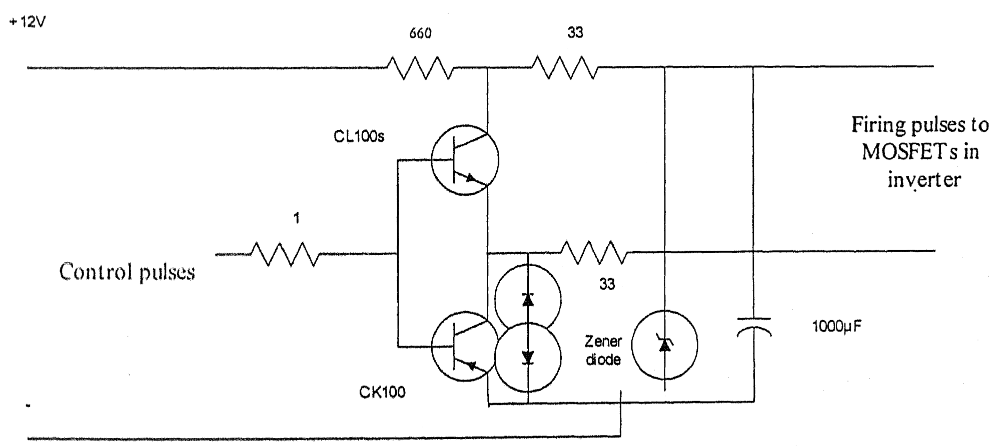

Fig 3.13 TTL circuit diagram

3.2.6 Output Waveforms:

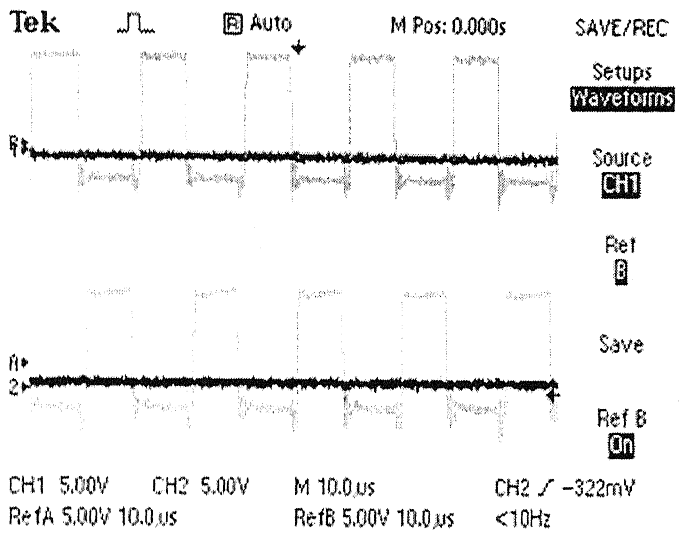

Fig 3.14 Output waveform of driver

3.3 Inverter:

An inverter produces an AC signal output from a DC input supply. Inverters are now common place in industry. Their uses include variable speed drives, induction heaters and uninterruptible power supply systems. The inverter used is of pulse width modulation type. In this type of inverter, the variation of output voltage is achieved by varying the duty cycle, or width of a train of pulses. This method, although simple produces a very coarse output voltage with high harmonic content. Full-bridge topology is used for the inverter. This inverter preferred over half bridge as the power ratings are high. With the same input voltage, the maximum output voltage of the full-bridge inverter is twice that of half-bridge inverter. This implies that for the same power, the output currents and the switch currents of full bridge inverter are one half of those of a half -bridge inverter.

3.3.1 Topology Selection:

A topology is an arrangement of the power devices and their magnetic elements. Each topology has its own merits within certain applications. Some of the factors which determine the suitability of a particular topology to a certain application are:

- Is the topology electrically isolated from the input to the output or not?
- How much of the input voltage is placed across the inductor or transformer?
- What is the peak current flowing through the power semiconductors?
- Are multiple outputs required?
- How much voltage appears across the power semiconductors?

The first choice is whether to have input to output transformer isolation. Non isolated switching power supplies are typically used for board level regulation where a dielectric barrier is provided elsewhere within the system. Non isolated topologies should also be used where the possibility of a failure does not connect the input power source to the fragile load circuitry. Transformer isolation should be used in all other situations. Associated with that is the need for multiple output voltages, transformers provide an easy method for adding additional output voltages to the switching power supply. The remainders of the factors involve how much stress the power semiconductors are being subjected. Fig 3.15 illustrates where the transformer isolated topologies are typically used within the power industry at various power and voltage levels. At reduced DC input voltages and at higher powers, the peak currents that must be sustained by the power switch grow higher which then affects the stress they must endure. The various areas show which topology best fits within that range of input voltage and output power that exhibits the least amount of stress on the power semiconductors.

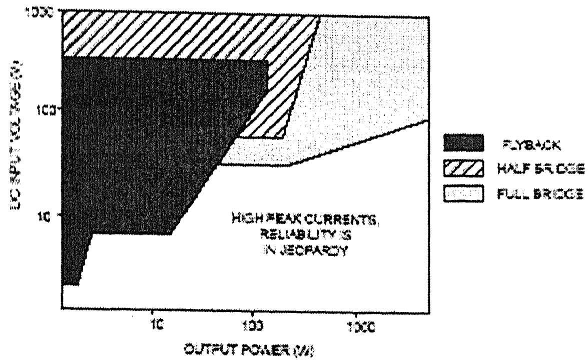

Fig 3.15 where various transformers isolated topologies can be used

From the Fig 3.15, it is observed that the full-bridge topology is best suitable for low input voltage and high output power applications. It is preferred over a half-bridge inverter because for an equivalent input voltage, the full-bridge inverter can provide twice the output voltage this implies that for equivalent power output, the output current is halved. The primary benefit of using a full bridge topology is its power handling capabilities, stability, and symmetry. The use of high frequency transformer is the most efficient way to step up the voltage. The full-bridge inverter is also significantly more controllable with the choice between bipolar and unipolar switching giving the designer choice between ease of operation or reduction in EMI.

3.3.2 Circuit Diagram and Operation

The Full bridge inverter shown in Fig. 3.16 is a higher power version of the half-bridge inverter, and provides the highest output power level of all the available topologies. The maximum current ratings of the power semiconductors will determine the upper limit of the output power of the half- bridge. These ratings can be doubled by using the full-bridge, which is obtained by adding another two switches and clamp

diodes to the half-bridge arrangement. At high power levels, it may be advantageous to use a full-bridge over a half-bridge converter to reduce the number of paralleled devices in the switch.

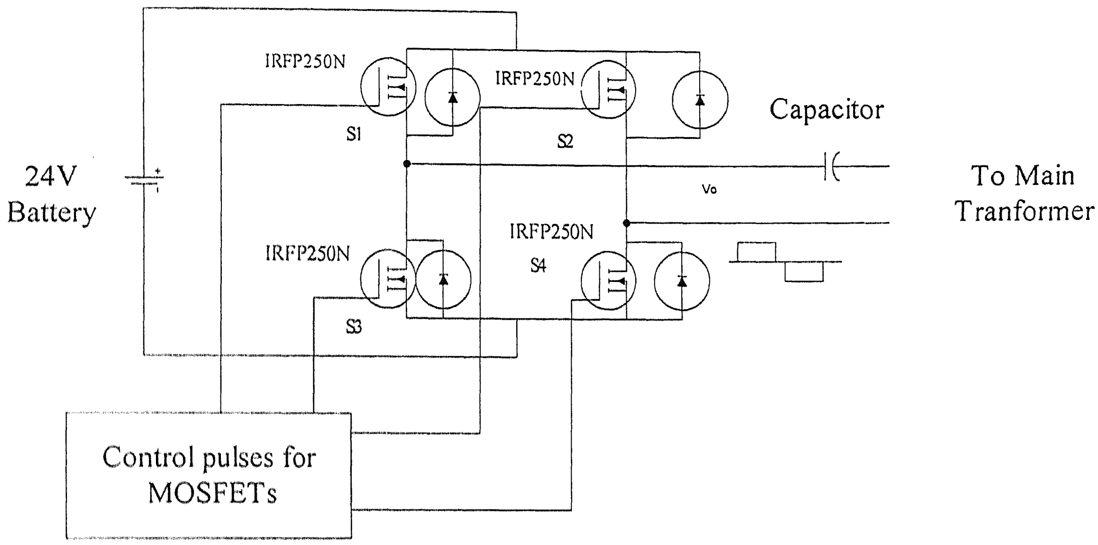

Fig 3.16 Full-bridge inverter

State	S1 and S4	S2 and S3	Vo	Mode
I	OFF	OFF	0	Freewheeling
II	OFF	ON	-24V	Power transfer
III	ON	OFF	+24V	Power transfer
IV	ON	ON	0	Freewheeling

Table 3.17 Switching state possibilities

The MOSFETs are driven alternately in pairs, S1 and S4, then S2 and S3. The transformer primary is subjected to the full input voltage. When the switches S1 and S4 are conducting, the positive voltage is applied across transformer primary which causes

the magnetizing current to increase. The switches S1 and S3 or S2 and S4 must not conduct simultaneously. Doing so would short the dc source, causing a shoot-through current spike. The switches cross conduction can lead to low efficiency and cause failure of switches. Cross conduction can be prevented by introduction of delay (Dead time) between the turn off of one switch and the turn on of the next switch in the same leg. The diodes connected in antiparallel with the switches ensure that the peak voltage across switching devices is limited to supply voltage, and also provide path for the current due to the energy associated with the transformer primary winding leakage inductance. When the switches S2 and S3 are conducting, the negative voltage is applied across the transformer primary and causes the magnetizing current to decrease. In full-bridge converter the utilization of transformer is good, leading to small core size. In particular, the utilization of transformer core is good, since the magnetizing current can be both positive and negative. Hence, the entire core B-H loop is used. Core balancing is achieved by placing a nonpolarized capacitor at the output of inverter. By using MOSFETs as switching elements, the on-voltage drops of the pairs in alternate half cycles may be unequal, the volt-second product is applied to the transformer primary in the alternate half cycles will be unequal and the core may walk off center of its hysteresis loop, saturate the core, and destroy the MOSFETs. The average DC voltage across the capacitor reduces the voltage across the primary winding in the direction of impending saturation. Core saturation at high power levels will cause instant destruction of the conducting power switches. Core saturation can also be avoided by using current programmed control. The series capacitor is omitted when current programmed control is used. The Full-Bridge is ideal for the generation of very high output power levels. It is

usually not used at low power levels because of its high parts count. The increased circuit complexity normally means that the full-bridge is reserved for applications with power output levels of 400W and above. For such high power requirements, designers often select power darlington, since their superior current ratings and switching characteristics provide additional performance and in many cases a more cost effective design. The full-bridge also has the advantage of only requiring one main's smoothing capacitor compared to two for the half-bridge. Isolated base drives are for each switch must be used. The full-bridge has the most complex and costly design out of all topologies, and should only be used where other types do not meet the requirements.

3.3.3 Choice of MOSFET:

Power MOSFETs are becoming increasingly more popular for use as power switches within switching power supplies. MOSFETs have some advantages over the bipolar transistor such as switching five to ten times faster than bipolar transistors and being easier to drive and use. Power MOSFETs are voltage driven devices that is their conductivity is determined by a voltage provided on its gate. MOSFETs can be driven directly from controller ICs that have totem pole output drivers with less than 100 ns switching times. The drive source, however, must be a well bypassed voltage source. This is because the gate of a MOSFET resembles a capacitor which must be charged and discharged in those 100 ns. So it must be capable of sourcing and sinking at least 1.5 ampere peak currents. Bipolar totem pole and CMOS drivers fill this need.

The MOSFET is used is IRFP250N. Some of the relevant data about this IC are as follows:

V_{DS} (max) =200V

I_{DS} (DC) = 30A

R_{DS} (on) = 0.075 Ω

Another useful feature of this IC is that it can operate at high frequencies up to 1MHz.

3.3.4 Output Waveform:

The waveform follows perfectly from theory and also has the associated "ringing". The cause of this ringing can be explained in several ways. It can be thought of as the electrical response of the circuit consisting of the inductance, resistance and capacitance of the load and cable to the pulse or it can be thought of as the interaction of pulses reflected back from the load with those coming from control circuit. The frequency of oscillation is very high. It doesn't really influence the circuit operation. All the associated components can withstand ringing and it gets filtered before the load block.

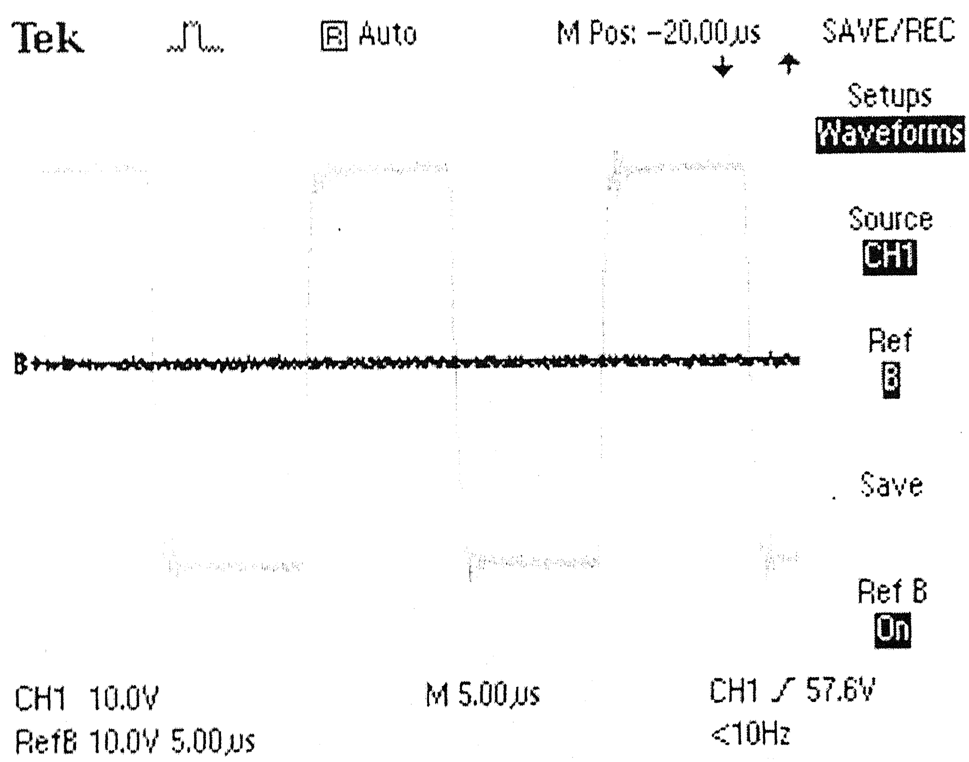

Fig. 3.18 Output waveform of inverter

3.4 Conclusion:

Complete analysis of the full-bridge inverter is taken up in this chapter. Operation of the inverter is explained along with its control circuit. The integrated PWM control IC UC3525AN is used to generate the control signals required to trigger the MOSFETs used in the inverter. The logic signals from the control circuit are transformed into power signals required to trigger power MOSFETs by using the driver circuit. The driver circuit also provides the electrical isolation between the control circuit and the power circuit. The isolated power supplies needed for the driver circuit are obtained by using a multi-output flyback converter. Experimental results of the flyback converter, inverter and its control circuit are presented.

Chapter 4

High Frequency Power Transformer

4.1 Introduction:

The design of magnetic elements forms the backbone of a good switching power supply design as proper electrical and physical design have large impact on reliable operation of power supply. The design of switched-mode transformer will determine the overall cost and efficiency of the power supply. A transformer makes use of Faraday's law: the induced emf equals the negative rate of time variation of the magnetic flux through the contour and the ferromagnetic properties of core to efficiently raise or lower AC voltages. Ferrite cores are preferred as they offer low core losses at high frequencies, good winding coupling, and ease of assembly. The power transformer used has 5 secondary windings as per the need for this application. These isolated power supplies are further rectified and smoothened to get +/- 12V, +/- 5 V and +230 V.

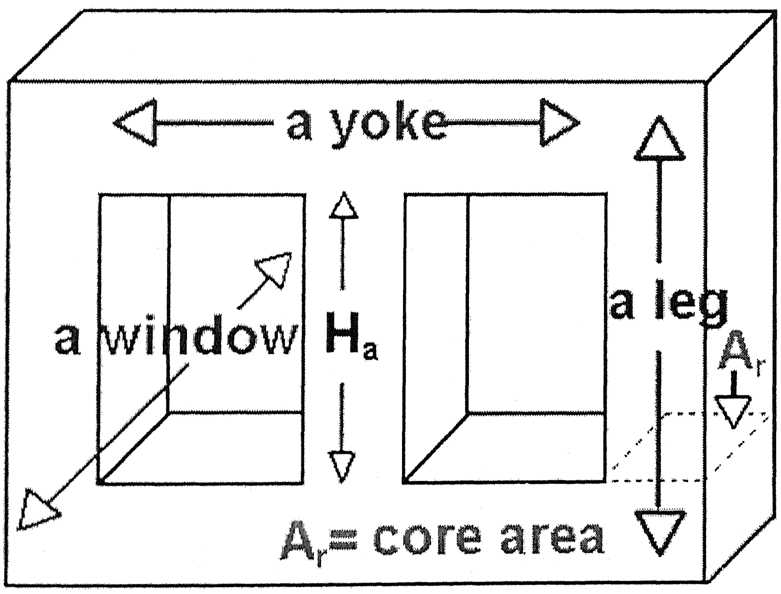

Fig 4.1 Main Transformer core

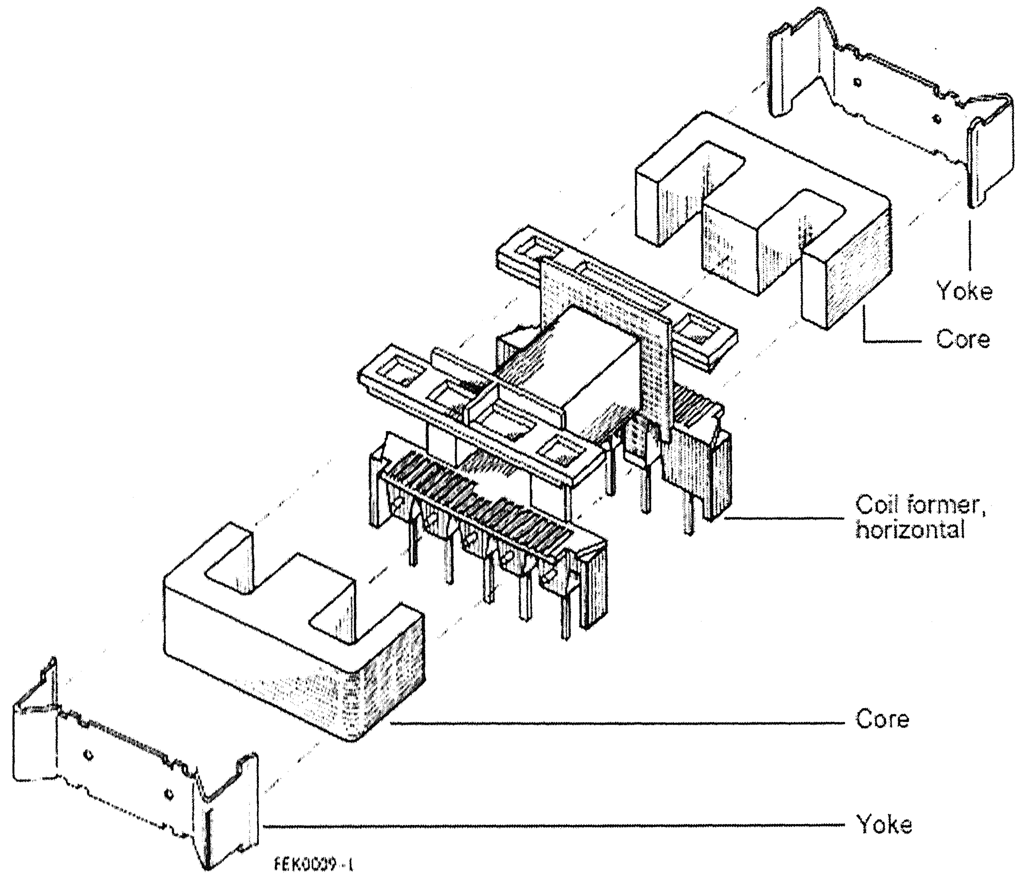

Fig 4.2 Assembly set using a coil former

4.2 High Frequency Transformer:

Whereas the invention of the semiconductor integrated circuits brought sudden and dramatic improvements in the size, cost and performance of electronic equipment, especially computers and portable telecommunication instruments, it also induced more requirements for the power supply system. Early minicomputer power supplies consisted of 50/60 Hz line frequency power transformer for high to low voltage transformation, followed by rectifiers and linear dissipative regulators. The line frequency power transformers were always big and heavy. In addition to inefficiency of the linear

regulators required large heat sinks for cooling, therefore adding more weight and size to the power supply. As long as electronic equipment itself was large, large size power supplies were not a critical problem. However, the size of the equipment itself became smaller through advances in semiconductor processing, bulky and inefficient power supplies wee therefore unacceptable. The operating frequency of power transformers suddenly jumped up from line frequency of 50/60 Hz to few tens kilohertz, even up to few hundreds kilohertz with the invention of high frequency power switch components and magnetic materials. These new semiconductor switches enabled the development of multi-kHz switching power converters which use smaller power transformers and filter components compared with their 50/60 Hz counterparts. The high frequency transformer provides the input to output isolation in the power stage of the converter. As with their low frequency counterparts, high frequency transformers provide a reliable and efficient form of converting one voltage level to another. The fundamental requirements of magnetic material for power transformers are the highest relative permeability, the largest saturation flux density, the lowest core loss, and the lowest remanent flux density. When the operating frequency of power transformer increased, the eddy currents inside magnetic cores become a critical problem. In order to minimize switching stresses, the high frequency transformer of SMPS is designed to operate at just under a 50% duty cycle on the switches. This allows for fluctuations in load and supply to be dealt with by decreasing or increasing the switch duty cycle. Just as low frequency transformer cores need to be laminated to reduce losses, high frequency cores need to be made of special materials. High frequency magnetic materials, such as ferrites and powder cores, have improved to suit the requirement of high frequency operations. The three electromagnetic

phenomena, eddy current flowing in the copper wires, leakage inductance between the primary and secondary windings, skin effects and proximity effects, are the obstacles for transformers operating at high frequencies. Eddy current is undesirable current inside the winding of transformers. It is the principal factor in introducing skin effects and proximity effects inside the copper windings, and strengthens the leakage inductance between the primary winding and secondary winding of high frequency transformers. Therefore, eddy current is the chief obstacle of high frequency transformer design. Unbalanced flux distortion is the other defect of high frequency transformer design. Magnetic flux concentrated in a particular area will decrease the coupling efficiency and increase the chance of getting hot spots inside the transformer. For this reason, it seems likely that commercial switching frequencies will be limited to few hundreds of kHz.

4.2.1 Introduction of Ferrite:

Ferrites are ceramic materials, dark gray or black in appearance and very hard and brittle. The magnetic properties arise from interactions between metallic ions occupying particular positions relative to the oxygen ions in the crystal structure of the oxide. In magnetite, in the first synthetic ferrites and indeed in the majority of present day magnetically soft ferrites the crystal structure is cubic, it has the form of the mineral spinal. The general formula of the spinal ferrite id $MeFe_2O_4$ where Me usually represents one or, in mixed ferrites, more than one of the divalent transition metals Mn, Fe, Co, Ni, Cu and Zn,or Mg and Cd. Other combinations, of equivalent valency, are possible and it is possible to replace some or all of the trivalent iron ions with other trivalent metal ions. Where high permeability and low loss are main requirements manganese zinc (MnZn)

ferrites and nickel zinc (NiZn) ferrites are used. These two compounds are still by far the most important ferrites for high permeability, low loss applications and constitute the vast majority of present day ferrite production. By varying the ratio of Zn to Mn or Ni, or by other means, both types of ferrites may be made in a variety of grades, each having properties that suit it to a particular application. The range of permeabilities available extends from about 15 for nickel ferrites to several thousand for some manganese zinc ferrite grades. The general magnetic properties of ferrite materials are:

- Permeability of several times
- A very high resistivity, generally, in excess of $10^8\ \Omega$ –m
- Saturation magnetization is appreciable, but significantly smaller than that of ferromagnetic materials
- Low coercive force
- Curie temperature varies from 100 °C to several hundred °C.
- Dielectric constant of the order of 10-12 at high frequencies with extremely low dielectric loss.

4.2.2 High Frequency Characteristics of Transformer Windings:

Transformers consist of magnetic core and coils. The main elements of transformer are magnetic cores and coil. The coil of transformers is actually a copper winding around the magnetic materials to generate the magnetic flux by the input power source and reproducible electric energy loading of the transformer. The arrangement of conductors in the winding of transformer is a very important factor to determine the dc resistance of the copper winding of transformers. When the operating frequency increases, the total numbers of turns decrease significantly. Therefore the total length of

the copper winding is also decreased dramatically. The power losses due to the DC resistance almost become zero. It is very good for power transformer design, however with the disappearing of the DC resistance, the AC resistance increases enormously. The power loss due to ac resistance is larger than the one generated from DC counterpart. When the operating frequency increased to few tens of kilohertz, the skin depth of the conductor reduces the effective cross section area of the wire and increases the ac resistance of the conductor. The ac resistance of the copper wire creates a heavy power loss in the windings of high frequency transformers. Furthermore, the proximity effects between conductors in the transformer winding structures become significant when the operating frequency is increased to few hundreds of kilohertz level.

The phenomenon of skin depth of the copper wire significantly increased the ac resistance of the wire, and the power loss of i^2R_{ac}, when the operating frequency of power transformers increased from line frequency to tens of kilohertz. The current density J in a conductor decreases exponentially with depth d.

$$J = e^{-d/\delta},$$

Where δ is a constant called the skin depth. Skin depth is defined as the depth below the surface of the conductor at which the current is 0.37 times the current at the surface. The skin depth is given by formula

$$\delta = \sqrt{\frac{\rho}{\pi\mu f}} \text{ or } \delta = \sqrt{\frac{2}{\omega\mu\sigma}}$$

Where μ is the permeability, σ is the conductivity, and ρ is the resistivity of the conductor.

The power loss can be reduced by using litz wires to replace the single copper wire. The term "Litz wire" is derived from a German word "litzendraht" meaning

woven wire. It is constructed of individually insulated copper wires either twisted or braided into a uniform pattern. Litz construction is designed to minimize the power losses exhibited in solid conductors due to skin effect. Skin effect is the tendency of high frequency current to be concentrated at the surface of the conductor. Litz constructions counteract this effect by increasing the amount of surface area without significantly increasing the size of the conductor. The usage of litz wires in high frequency power transformers significantly reduces the power loss of $i^2R_{ac.}$ There is another electromagnetic phenomena appeared in transformer windings, it is proximity effect. Proximity effect is an eddy current effect in a conductor due to alternating magnetic field of other conductors in the vicinity. There is a tendency for current to flow in loops or concentrated distributions due to presence of magnetic fields generated by nearby conductors. In transformers and inductors, proximity effect losses are generally more significant than skin effect losses. The power losses created by proximity effect in the windings of high frequency power transformers can be reduced by arranging in sandwich winding structure.

Another phenomenon that is appeared in transformer windings is leakage inductance. The leakage inductance is given by

$$L \; \alpha \; \frac{1}{M^2} \frac{h_w}{b_w}$$

Where M is the number of section interfaces. If the number of section interfaces increases, the leakage inductance decreases. The relationship between them is that the leakage inductance is inversely proportional to the square of number of section interfaces of the winding. According to this relationship, the special winding structure with interleaving is used to reduce the leakage inductance.

4.2.3 Functions of a Transformer:

The purpose of a power transformer in switched-mode power supplies is to transfer power efficiently and instantaneously from an electrical source to a load. In doing so, the transformer also provides important additional capabilities:

- The primary to secondary turns ratio can be established to efficiently accommodate widely different input/output voltage levels.
- Multiple secondaries with different numbers of turns can be used to achieve multiple outputs at different voltage levels.
- Separate primary and secondary windings facilitate high voltage input/output isolation, especially important for safety in off-line applications.

4.2.4 Design Flow of Magnetic Elements:

- Select the core material appropriate for the application and for the frequency of operation.
- Select the desirable core style that will meet the needs of the application.
- Determine the size of core needed to provide the required output power of the supply.
- Determine whether air gap is needed and calculate the number of turns needed for each winding.
- Wind the magnetic component using the described physical winding technique.
- During prototype stage, verify its operation with respect to the level of voltage spikes, cross regulation, output accuracy and ripple, and RFI

4.3 Transformer Design:

4.3.1 Specifications:

Primary side

24V & 20 A

secondary side

Voltage	Current
+5V	20A
-5V	0.5A
+12V	7.2A
-12V	0.5A
+230V	0.8A

4.3.2 Design Parameters:

Frequency= 50 kHz

Input voltage =24V

Core area, A_c= 540 mm^2

Window area, A_w= 562.5 mm^2

4.3.3 Calculations:

Using $V_1 = 4.44 f B_{m1} A_c N_p$

V_1=24V

$B_{m1} * N_p = 24 / (4.44*50*10^{3*} 5.4*10^{-4})$

$=0.2002$

N_1 has taken as N_p=12, Bm1 comes out to be 0.01668T (which is well within the saturation).

For +/- 5V winding

By considering the voltage drop in rectifier (1V), this winding is designed for 6V.

$$\frac{V_o}{V_{in}} = 2\frac{N_1}{N_p}D$$

taking duty cycle D=0.45

$N_1 = 6*12 /(2*24*0.45) = 3.33 \approx 4$

For +/- 12V winding

By considering the voltage drop in rectifier (1V), this winding is designed for 13V.

$$\frac{V_o}{V_{in}} = 2\frac{N_2}{N_p}D$$

Taking duty cycle D=0.45

$N_2 = 13*12 / (2*24*0.45) = 7.22 \approx 8$

For +230 V winding

By considering the voltage drop in rectifier (4V), this winding is designed for 234V.

$$\frac{V_o}{V_{in}} = 2\frac{N_3}{N_p}D$$

Taking duty cycle D=0.45

$N_3 = 234*12 / (2*24*0.45) = 130$

Cross section area of primary wire:

Knowing J(current density of copper) ≈ 3 A/mm^2,

Cross section area of the wire $a_{wp}=I_p$ / J =20/3=6.67 mm^2

Hence, the diameter of the wire =2.914 mm

SWG wire has to be used = SWG11

No. of Litz wires used (SWG24) = 26

Cross section area of secondary wires:

Case 1: +12V

Current =7A

Knowing J(current density of copper) ≈ 3 A/mm^2,

Cross section area of the wire $a_{ws1}=I_{s1}$ / J =7.2/3=2.4 mm^2

Hence, the diameter of the wire = 1.748mm.

SWG wire has to be used =SWG15

No. of Litz wires used (SWG24) =10

Case 2: -12V

Current= 0.5A

Knowing J(current density of copper) $\approx$ 3 A/mm^2,

Cross section area of the wire $a_{ws2}=I_{s2} / J = 0.5/3=0.333mm^2$

Hence, the diameter of the wire =0.4606mm.

SWG wire has to be used =SWG25

No. of Litz wires used (SWG25) =1

Case 3: +5V

Current= 20A

Knowing J(current density of copper) $\approx$ 3 A/mm^2,

Cross section area of the wire $a_{ws3}=I_{s3} / J = 20/3=6.67\ mm^2$

Hence, the diameter of the wire = 2.914mm.

SWG wire has to be used =SWG11

No. of Litz wires used (SWG24) =26

Case 4: -5V

Current= 0.5A

Knowing J (current density of copper) $\approx$ 3 A/mm^2,

Cross section area of the wire $a_{ws4}=I_{s4} / J = 0.5/3=0.166\ mm^2$

Hence, the diameter of the wire = 0.4606 mm.

SWG wire has to be used =SWG25

No. of Litz wires used (SWG25) =1

Case 5: +230V

Current =0.8A

Knowing J(current density of copper) $\approx$ 3 A/mm^2,

Cross section area of the wire $a_{ws5}=I_{s5} / J = 0.8/3 = 0.266mm^2$

Hence, the diameter of the wire = 0.5827 mm.

SWG wire has to be used =SWG23

No. of Litz wires used (SWG23) =1

4.4 Winding Specifications:

Winding	Voltage	No. of Turns	Diameter	SWG wire used	No of conductors Used
Primary	24V	12	2.90 mm	SWG 11	**26**
Secondary	+5V	4	2.914mm	SWG11	**26**
Secondary	+12V	8	1.748mm	SWG15	**10**
Secondary	-5V	4	0.4606mm	SWG25	**1**
Secondary	-12V	8	0.4606mm	SWG25	**1**
Secondary	+230V	130	0.5827mm	SWG23	**1**

Table 4.3 Winding specifications of the transformer

4.5 Diagram with Specifications:

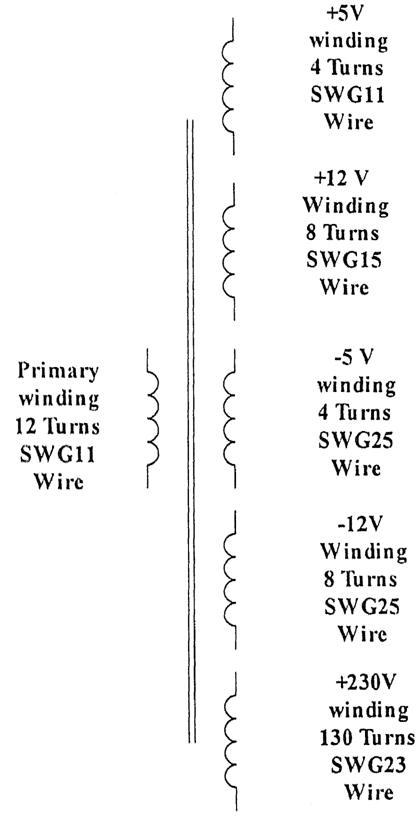

Fig 4.4 Transformer diagram

4.6 Core Details:

EE65/32/27 Core

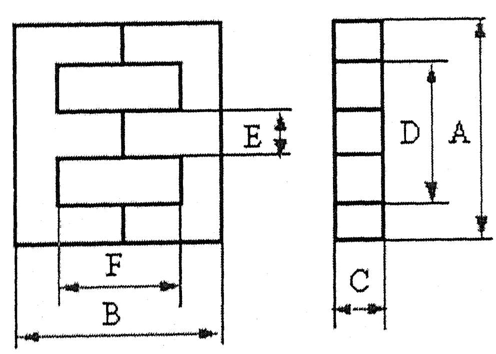

Fig 4.5 EE Core

A = 65.0 ± 1.3 mm

B = 65.0 ± 0.6 mm

C = 27.3 ± 0.7 mm

D = 44.2 mm (min)

E = 19.65 ± 0.35 mm

F = 45.1 ± 0.7 mm

4.6.1 Magnetic Characteristics of Core:

$\sum \frac{l}{A}$ =0.27 mm^{-1}

l_e =147 mm

A_e =535 mm^2

A_{min} =529 mm^2

V_e = 78600 mm^3

Approx. weight 394 g/set

4.6.2 Material used for Core:

N67 material.

The cores made of N67 material can be used for the frequency range from about 100 to 300 kHz.

4.7 Conclusion:

The use of high frequency power transformer is to transfer the output square wave voltage of the inverter output into the various voltage levels required for the CPU and monitor of the personal computer. Ferrite core is used for the transformer as the operating frequency is high (50 kHz). The use of ferrite core minimizes the effect of eddy currents. The transformer is wound with litz wires to minimize the skin effect, proximity effect and leakage inductance .The design of the transformer core and windings is presented in this chapter.

Chapter 5

Rectifiers, Filters and Closed-loop Operation

5.1 Introduction:

The most common type of secondary voltages that have to be rectified in a switching power supply are high frequency square waves, which in turn require special components, such as schottky or fast recovery rectifiers, Low ESR capacitors, and energy storage inductors, in order to produce low noise outputs.

5.2 Rectifiers:

Rectifiers are found in all DC power supplies that operate from AC voltage source. Simplest rectifiers are the ones in which diodes are used. Diodes have the ability to conduct current in one direction and block current in the other direction.

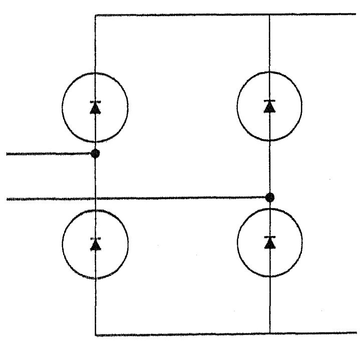

Fig 5.1 Rectifier

Rectifiers play a critic role inside switched-mode power supplies. The switching power supply demands that power rectifier diodes must have low forward voltage drop, fast recovery characteristics, and adequate power handling capability.

Ordinary PN junction diodes are not suited for switching applications, basically because of their slow recovery and low efficiency. The types of rectifier diodes are commonly used in switched-mode power supplies.

1) High-efficiency fast recovery,

2) High-efficiency very fast recovery,

3) High-efficiency ultra fast recovery diodes

4) Schottky barrier rectifiers.

5.2.1 List of Diodes used:

Since the power requirements are different for each rectified output, the rectifier diodes of appropriate ratings are chosen as shown in the table below

Voltage	Switch used(Name of IC)	Quick Reference Data
+12V	PBYR2045CT	VR=40V/45V,Io(AV)=20A
-12V	IN5822	VRRM=40V,IF(AV)=3.0A
+5V	30CPQ080	VRRM=80V,IF(AV)=30A
-5V	IN5822	VRRM=40V,Io(AV)=3.0A
+230V	RM25HG	VRRM=1100V,Io(AV)=25A

Table 5.2 Rectifier diodes used and their quick reference data

5.3 Filtering:

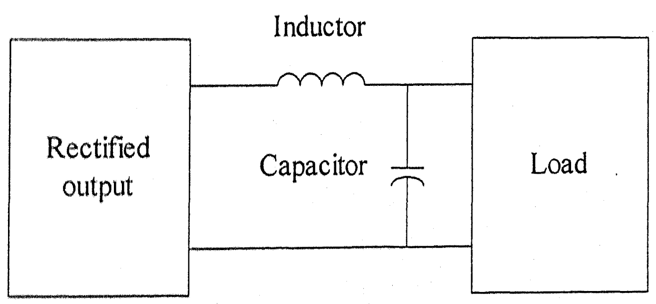

Fig 5.3 Filter module

The power supply for personal computer needs good voltage regulation. An LC low pass filter is used to filter output ripples. An inductor is used in a filter to reduce the ripple in current. This reduction occurs because current through the inductor cannot change suddenly. When the current through an inductor tends to fall, the inductor tends to maintain the current by acting as a source. Inductors used in switched-mode power supplies are usually wound on toroidal cores, often made of ferrite or powdered iron core with distributed air-gap to minimize core losses at high frequencies.

A capacitor is used in a filter to reduce ripple in voltage. Since switched power regulators are usually used in high current, high-performance power supplies, the capacitor should be chosen for minimum loss. Loss in a capacitor occurs because of its internal series resistance and inductance. Capacitors for switched regulators are chosen on the basis of equivalent series resistance (ESR). Most of applications use electrolytic capacitors, preferably of the low ESR type. The ESR of the filter has a direct effect on the output ripple and also on the life of capacitor itself. Since the ESR is a dissipative element, the power loss in it generates heat, which in turn shortens the capacitor's life. For very high performance power supplies, sometimes it is necessary to parallel capacitors to get a low enough effective series resistance.

The rate of the charge for the capacitor is limited by the low impedance ac source (the transformer), by small resistance of the diode, and by the counter electromotive force (CEMF) developed by the coil. When the pulsating voltage is applied to LC filter, the inductor produces a CEMF which opposes the constantly increasing input voltage. The net result is to effectively prevent the rapid charging of the filter capacitor. Thus, instead

of reaching peak value of the input voltage, the capacitor charges to the average value of the input voltage.

5.3.1 Choice of L & C:

The value of the filter capacitor must be relatively large to present opposition (X_C) to the pulsating current and store a substantial charge. The larger the value of the capacitor filter capacitor better is the filtering action.

The voltage from the secondary of transformer is rectified and it is observed that there are ripples of 100 kHz overriding DC Voltage. So the filter is designed to filtering out all the frequency components of 100 kHz and above.

Transfer function T as follows.

$$T = \frac{Vout}{Vin} = \frac{\frac{1}{j\omega C}}{j\omega L + \frac{1}{j\omega C}}$$

Or, $T = \dfrac{1}{1-\omega^2 LC}$

In order to filter out 100 KHz and higher frequencies, ω_o is selected as

$$\omega_o = \frac{1}{\sqrt{LC}} = \frac{2\pi f_o}{10} = 62831.85 \text{ rad/sec}$$

Therefore, $LC = 2.533 * 10^{-10}$

By Choosing C = 47 μF, L= 5.389 μH.

The Bode plot for T= $\frac{1}{1-2.25*10^{-10}*\omega^2}$ is as shown in fig 5.4

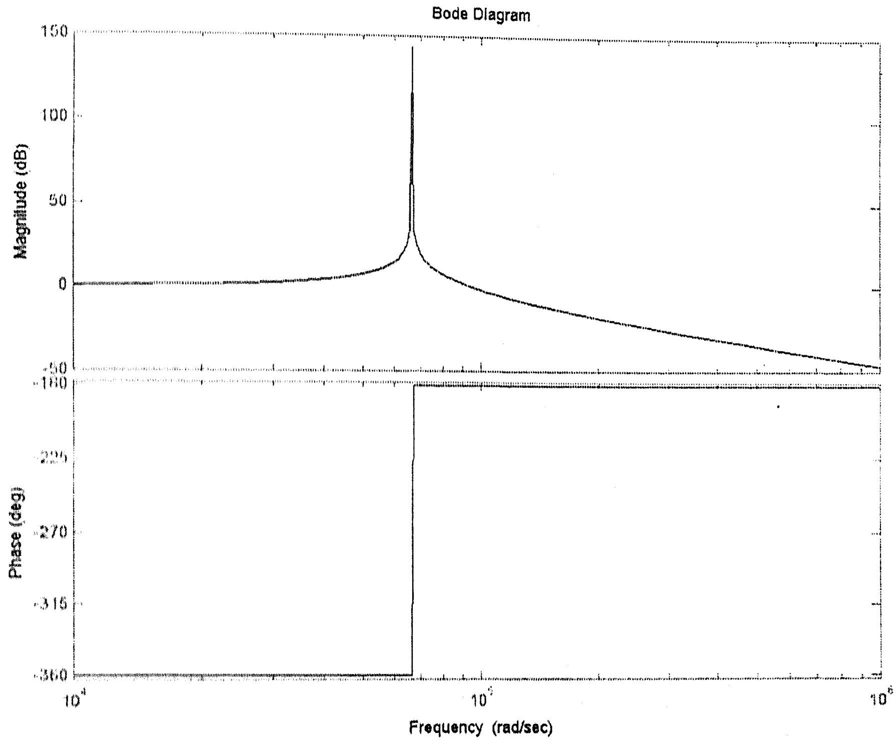

Fig 5.4 Magnitude and phase plot for LC filter

5.3.2 Inductor Design:

A torrid core has been used for the inductor used in filter. A toroid of round cross-section offers better performance than one of rectangular cross-section. The symmetry of their circular geometry minimizes the amount of external magnetic flux produced. Consequently, they produce much lower amounts of unwanted electromagnetic interference. The mean turn length will be shorter than that of other core types of equal power capability, hence lower winding resistance and lower winding losses. Compared against other core types, toroidal coil has a lot of surface area from

which it can dissipate heat, hence it cools much better than other core types. Because of their circular nature, the magnetic path of a toroid is an unbroken continuous path unless intentionally broken. An air gap may be introduced to eliminate flux saturation in the core.

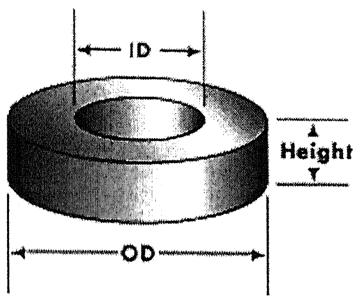

Fig 5.5 Toroid core

$$L = \frac{\mu_o \mu_r N^2 h}{2\pi} \ln(\frac{OD}{ID}),$$

Where, N = number of turns

h= height of the toroid

OD = outer diameter of toroid

ID = Inner diameter of toroid

L = 5.389 μH.

By substituting, OD=27mm, ID=15mm, $\mu_r = 100$, h=10mm=0.01m

$$N^2 = \frac{45.84}{\mu_r h} = 45.84.$$

N= 6.77 ≈ 7 turns.

5.4 Closed-loop Operation:

The heart of every switching power supply is a negative feedback loop which regulates the output voltages within a specified tolerance band (e.g., ± 1% around its nominal value) in response to changes in output load and the input line voltages. To accomplish this, an error amplifier is used, which attempts to minimize the error between the output voltage and an ideal reference voltage by adjusting the duty ratio of the switches in inverter. The error amplifier must respond to changes in load voltages or input voltage variations quickly and without oscillating. If the error amplifier takes too long to respond to these changes, the supply behaves sluggishly. If the response speeded up, the supply reaches a point where it may oscillate. The demands of load cause the output voltages to rise or fall, the error amplifier changes the energy through the supply to maintain specified output. The error amplifier must respond to these non-DC effects by having gain at higher frequencies. Every feedback controller has a different strategy, but all use the closed-loop control algorithm – measure a process variable, decide if its value is acceptable and apply a corrective effort as necessary. The main advantages of using closed loop control are that it provides greater stability and gives much better repeatability.

5.4.1 Types of Feedback Control:

There are basically two types of feedback control.

1. Single loop control,
2. Multi loop control.

Single loop control is commonly called voltage mode control. In this mode of control the output voltage is sensed and compared with a reference voltage and the error

is compared with a fixed frequency saw tooth waveform in order to control the switch duty ratio adjusts the voltage across transformer and brings the output voltage to reference. In current mode control, an additional inner control loop is used. In this type of control, either the inductor current or switch current, which is proportional to the output current, is measured and compared with the control voltage.

5.4.2 Stability Criteria applied to Power Supplies:

The rule of stability when applied to power supplies is" Whenever the closed loop gain is greater than or equal to 1, the closed loop phase shall never come to within 30° of 360°".

At gain cross over frequency (unity open loop gain), the amount by which phase shift is less than 360° is called the phase margin. Systems that exhibit phase shifts of greater than330° are considered "metastable". These systems will break out into oscillation if they are impinged with a small transient, or will at least ring in an undamped fashion. For real world systems, the maximum phase shift should be no greater than 300° to 315° or 45° to 60° away from 360°. Within this range, the supply will respond to transient changes in the operating point in a slightly underdamped and to slightly overdamped fashion.

5.4.3 Working:

The gating signal for MOSFETs is generated by comparing the ramp wave from oscillator with the control voltage, which is obtained by multiplying the difference of divided down output voltage and reference voltage with a proper gain. . As all the voltages are

derived from same transformer, only +5 volt output is controlled, while the other output voltages follow the changes in +5 volt output.

If the final output voltage increases, the control voltage also increases, thus the pulse width of the signal is decreased which increases the freewheeling time for the inverter. Due to decrease in on time period of the inverter, the voltage output is bound to fall. If the output voltage decreases, the control voltage also decreases, thus the pulse width of the signal is increased which decreases the freewheeling time for the inverter. Due to increase in on time period of the inverter, the voltage is bound to rise.

5.4.4 Circuit Implementation:

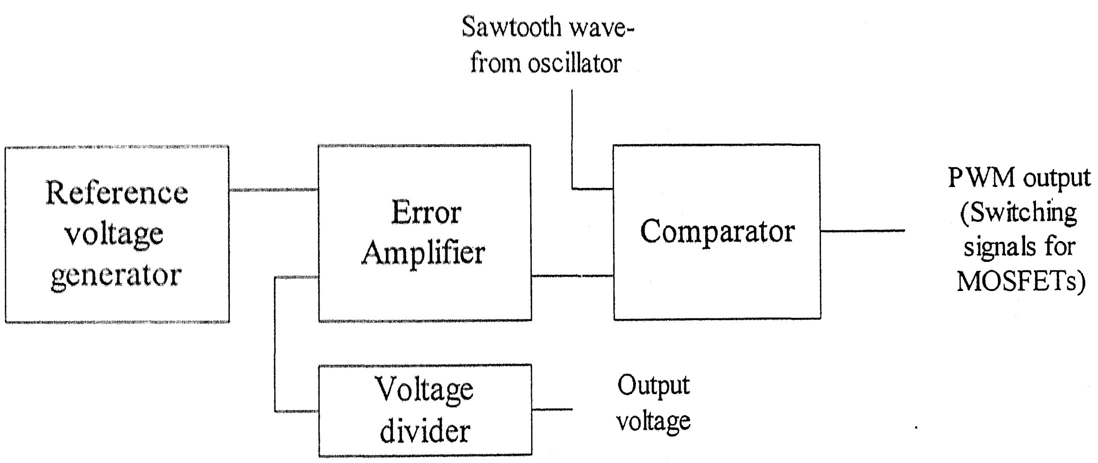

Fig 5.6 Block diagram of closed loop control system

5.4.5 Reference Voltage Generator:

The constant reference voltage is obtained from the reference regulator in IC UC3525AN. A constant voltage of 5V is available at the output of reference regulator (pin 15) and this voltage is divided by a trimmer and applied to the inverting input of error amplifier.

5.4.6 Error Amplifier:

The main function of error amplifier is to provide proper gain to the difference between the inverting and non inverting inputs of the error amplifier. The output of error amplifier(Ve) can be calculated by using the formula

$$\text{Ve} = \frac{Vo(1+\frac{R4}{R3})}{(1+\frac{R2}{R1})} - Vref * \frac{R4}{R3}$$

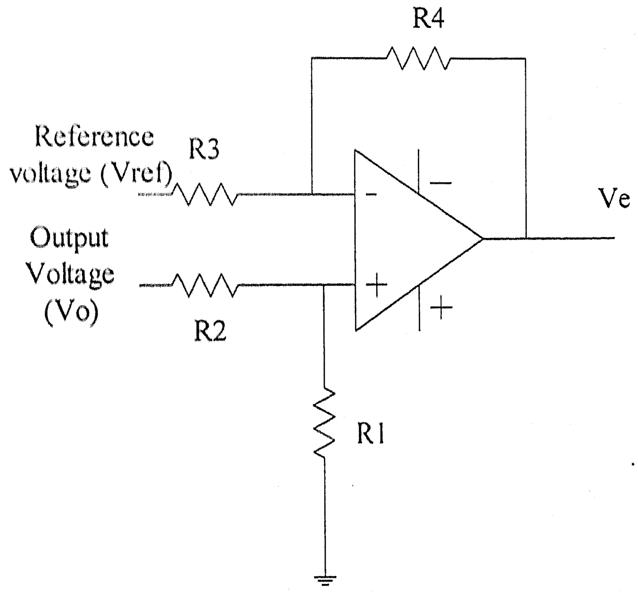

Fig 5.7 Error generator circuit

5.4.7 Comparator:

The main function of the comparator is to compare the ramp wave generated by oscillator with the output of error amplifier.

5.4.8 Voltage Divider:

Voltage divider is a network consists of resistors and the reduced voltage is applied at the non inverting input of the error amplifier.

5.5 Conclusion:

The rectifier converts high frequency AC voltage from the inverter to the DC voltages required for the CPU and monitor of the personal computer. The rectifier uses schottky diodes, as they are characterized by fast recovery time and low voltage drop. LC low pass filter is used to eliminate the harmonics in the DC output voltage of the rectifier. Closed loop control can be used to stabilize the power supply. As the +5V voltage is the most important, it is sensed and according to that the duty cycle of the inverter is adjusted.

Chapter 6

Results, Conclusions and Future Scope of Work

6.1 Results:

The project was started with an aim of developing prototype with a closed loop controlled regulated voltage outputs capable of meeting the power needs of a personal computer. The idea came up with a system that can integrate the external UPS into computer switching power supply. The system is simulated using MATLAB and PSIM softwares. The present chapter gives the simulation results, experimental prototype and experimental results of the developed power supply in the laboratory.

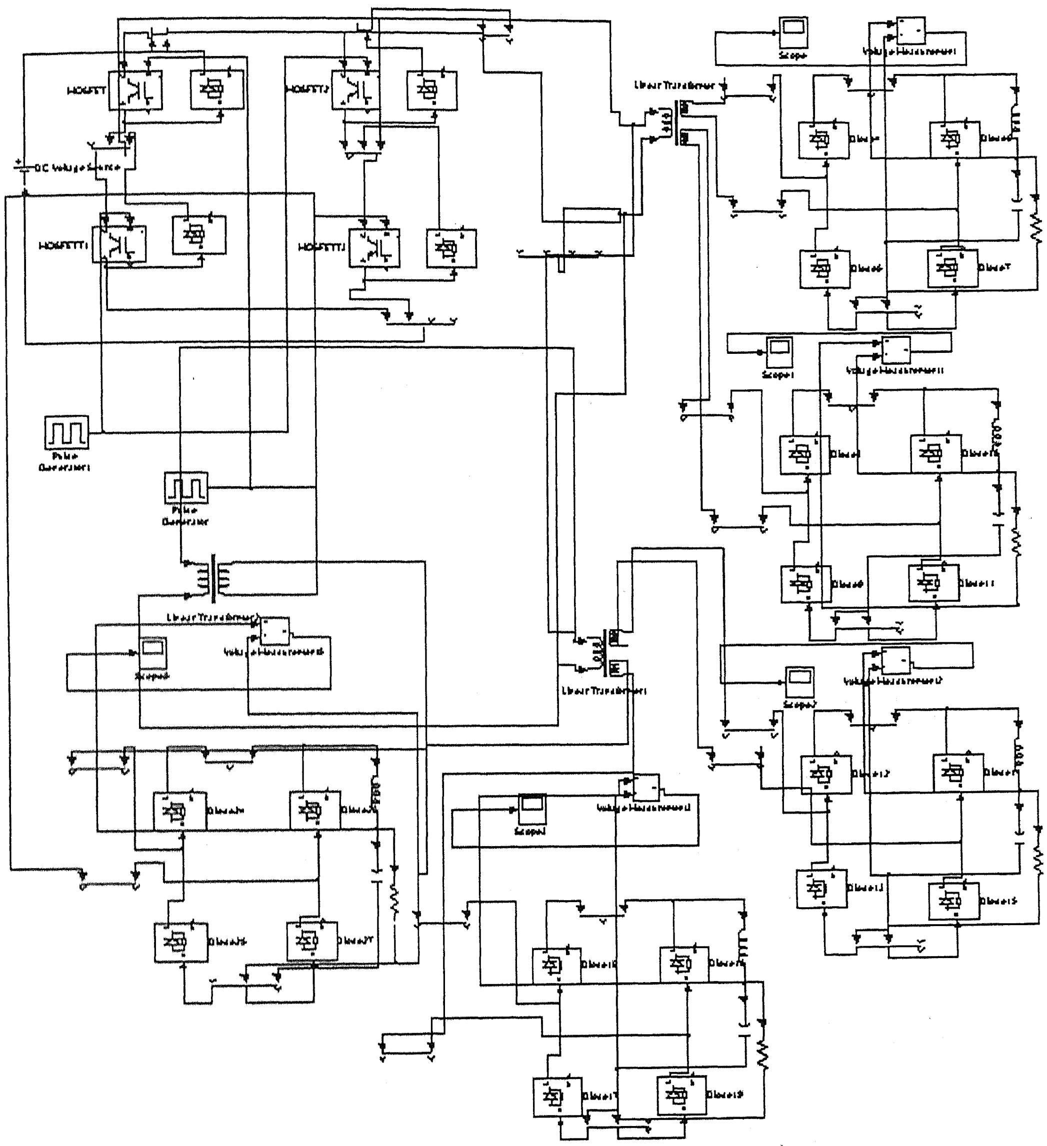

Fig 6.1 Complete circuit under simulation (MATLAB SIMULINK)

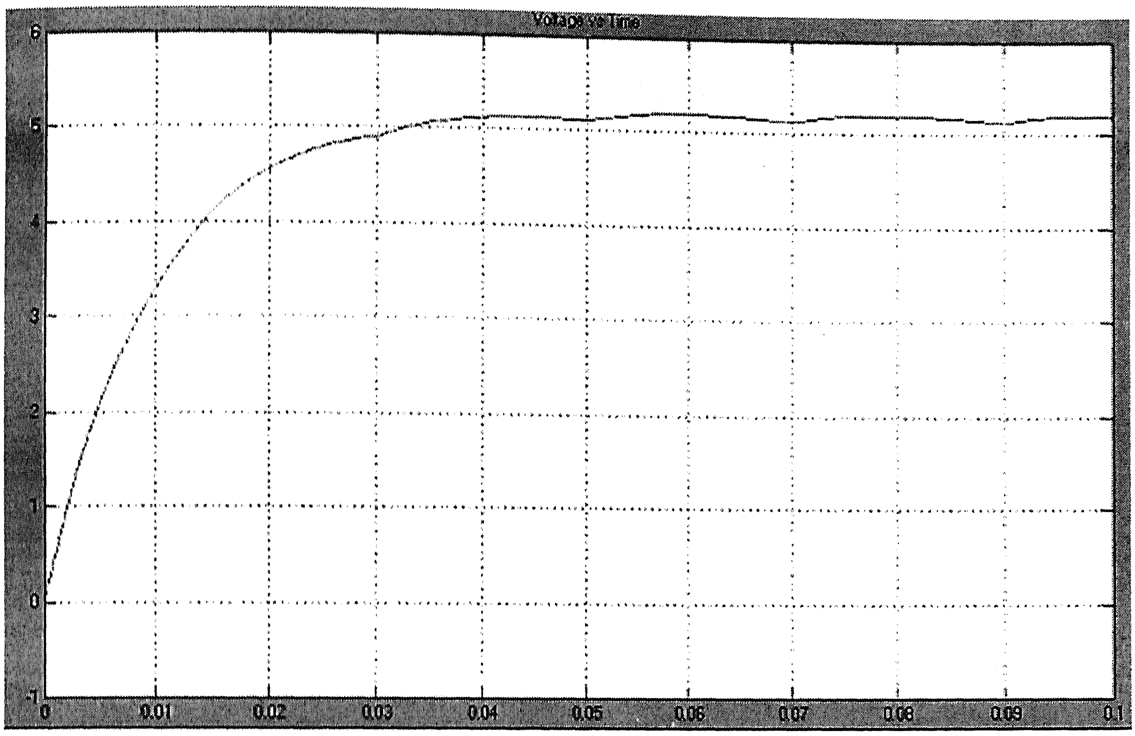

Fig 6.2 Simulated +5V output waveform for CPU

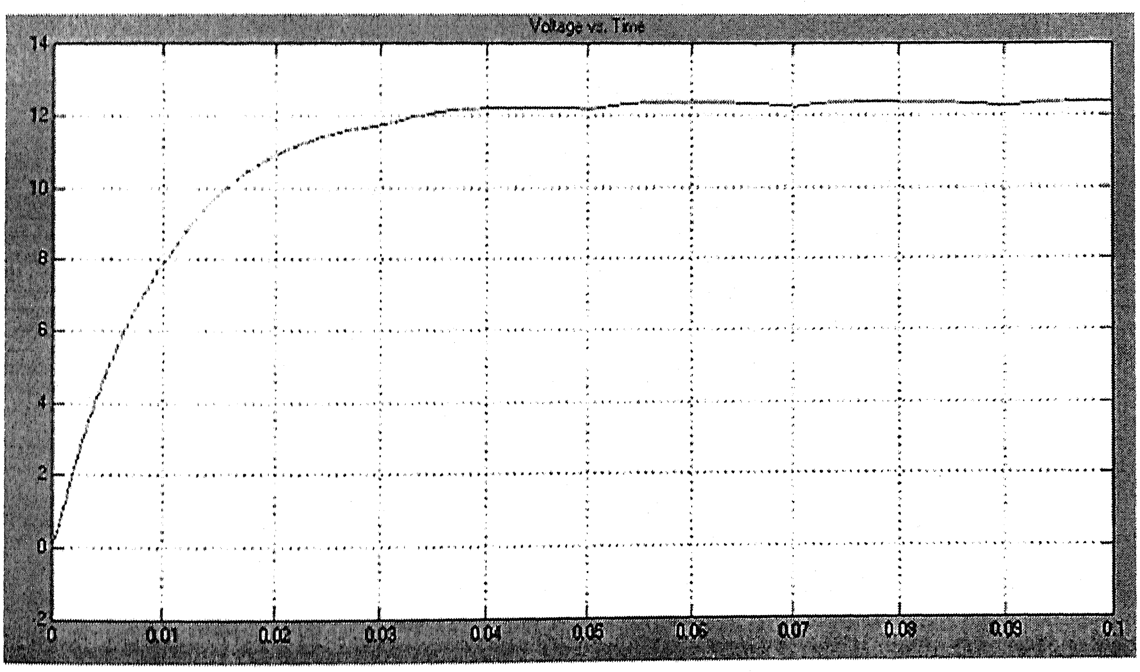

Fig 6.3 Simulated +12V output waveform for CPU

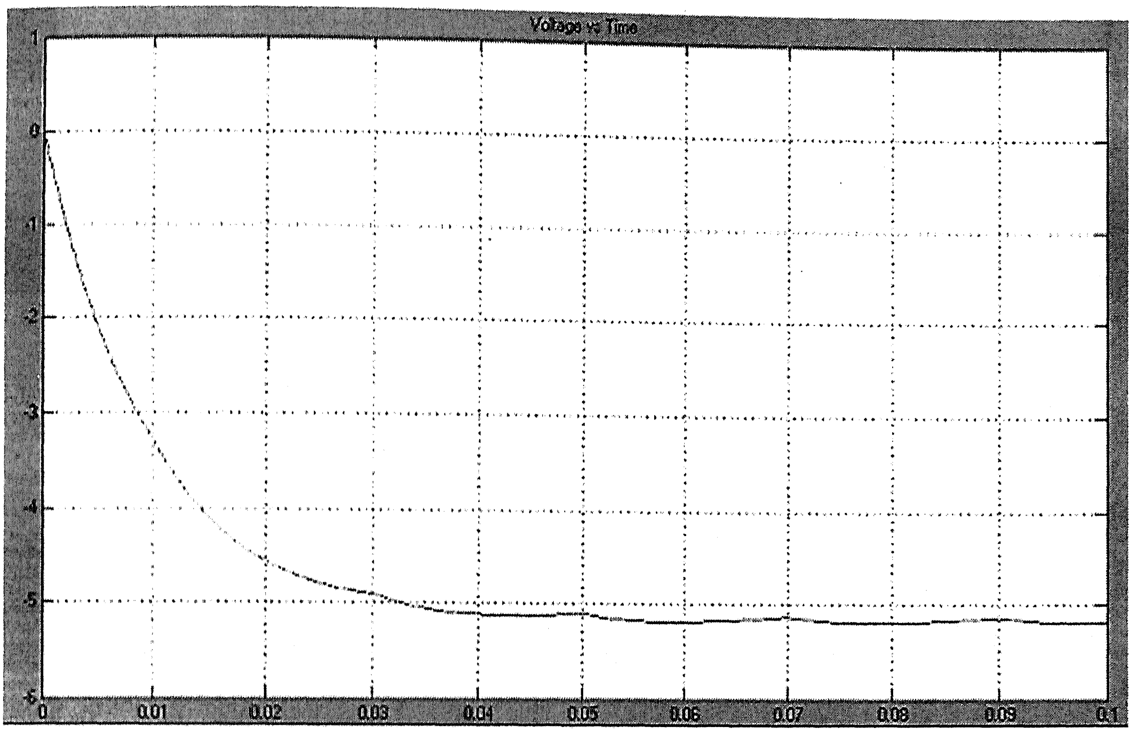

Fig 6.4 Simulated -5V output waveform for CPU

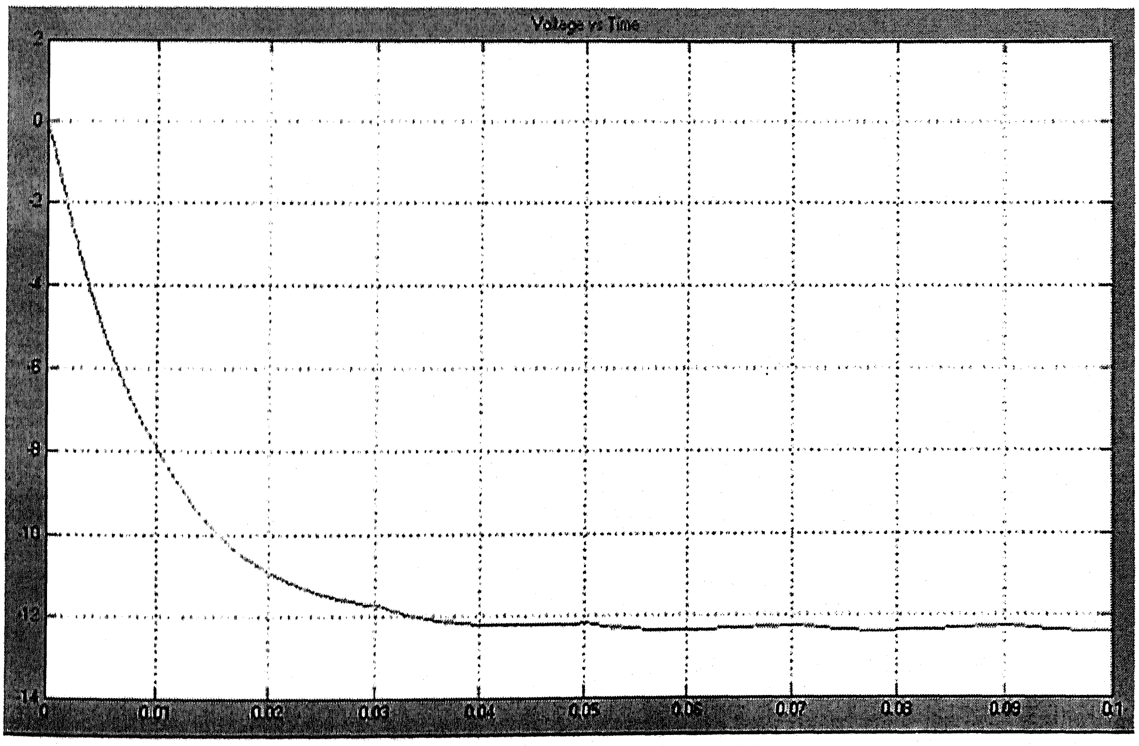

Fig 6.5 Simulated -12V output waveform for CPU

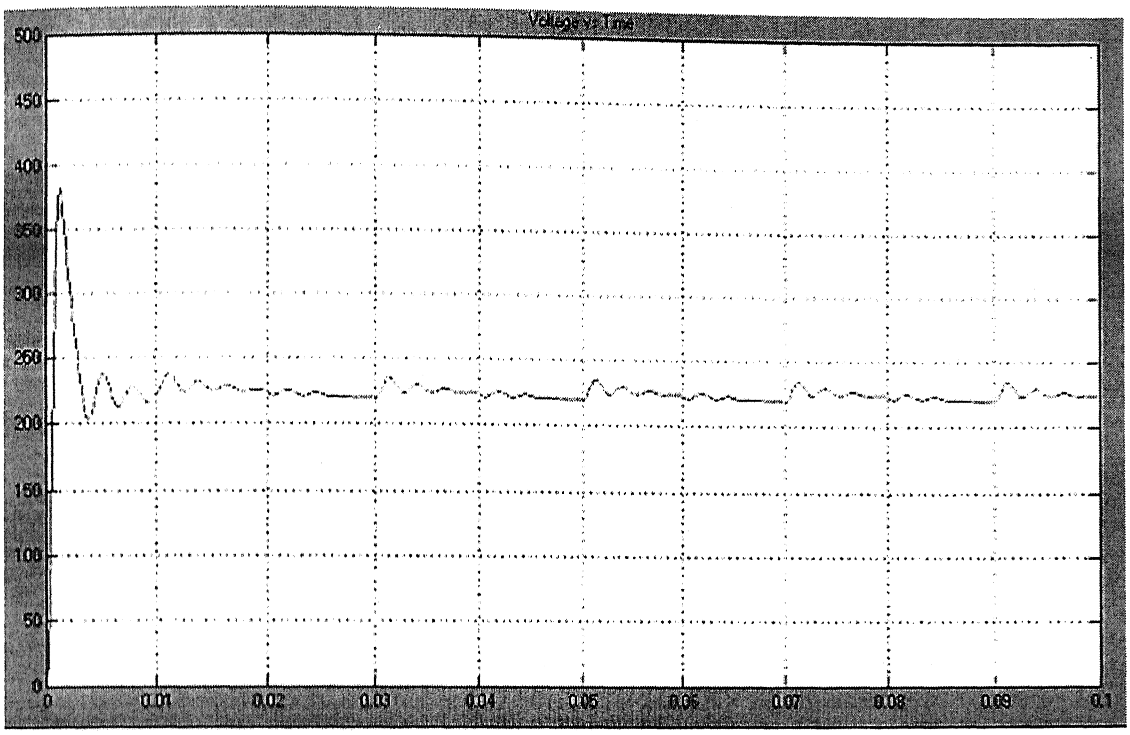

Fig 6.6 Simulated +230V output waveform for Monitor

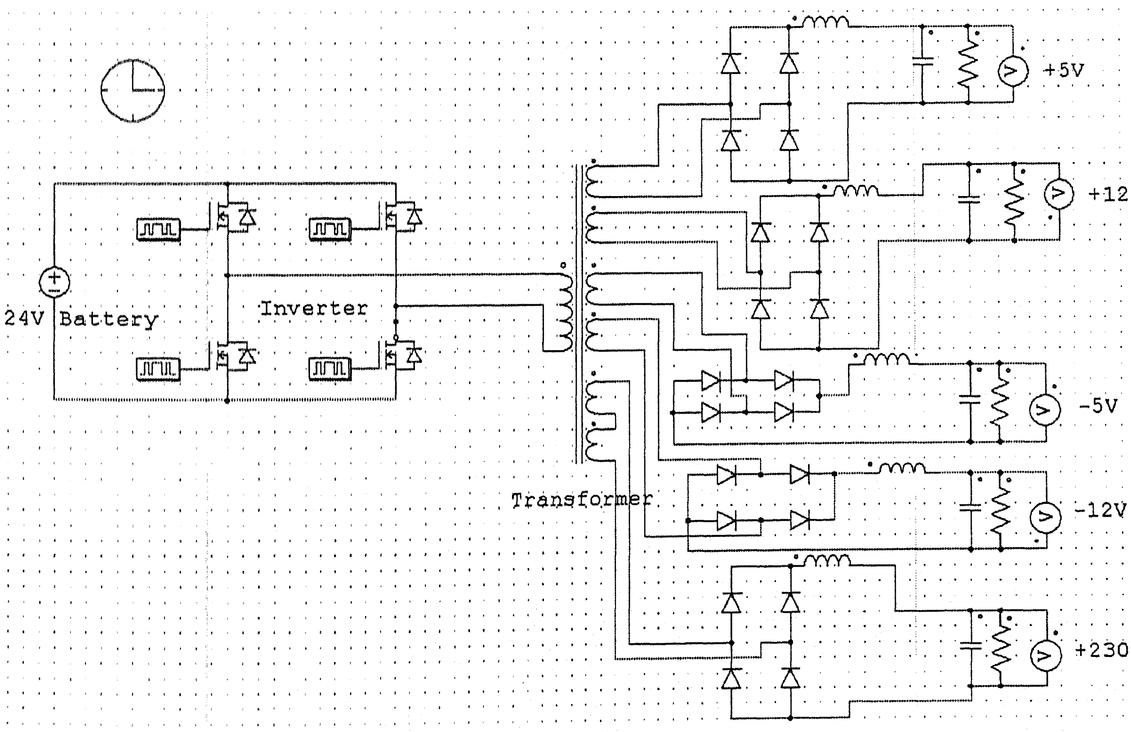

Fig 6.7 Complete circuit under simulation (PSIM)

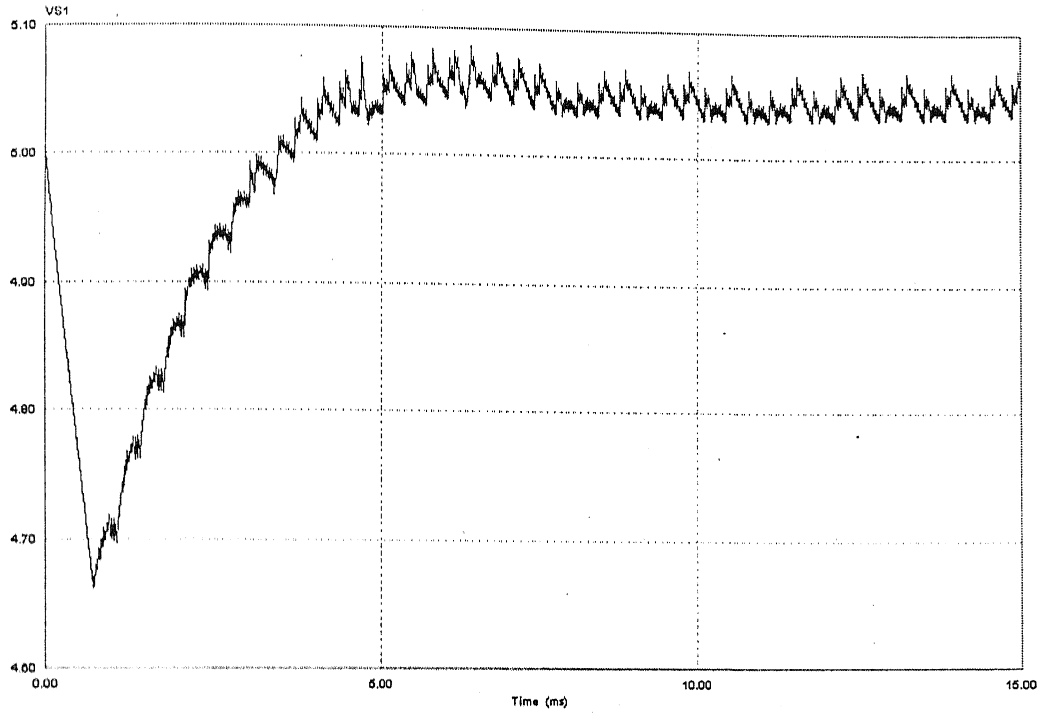

Fig 6.8 Simulated +5V output waveform for CPU

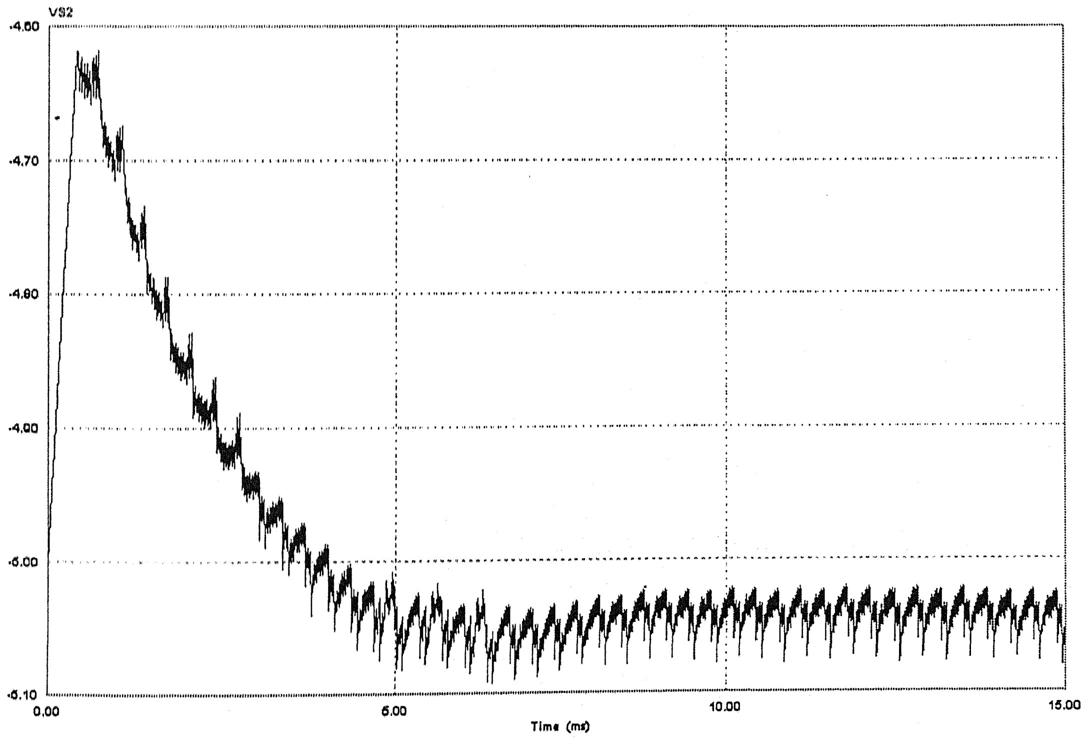

Fig 6.9 Simulated -5V output waveform for CPU

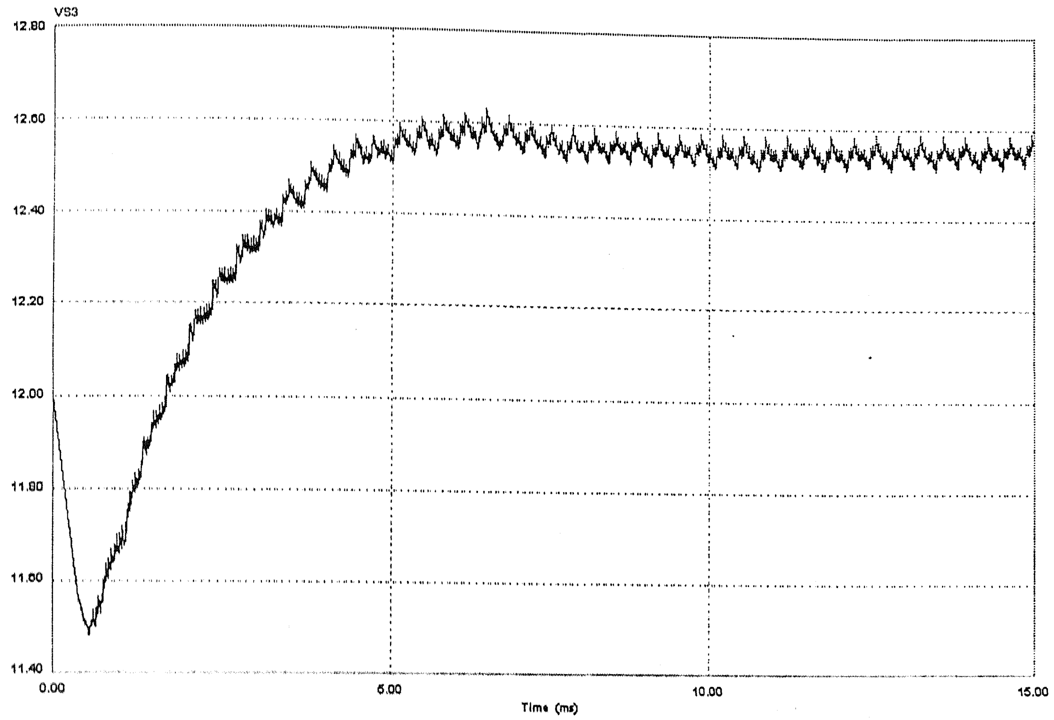

Fig 6.10 Simulated +12V output waveform for CPU

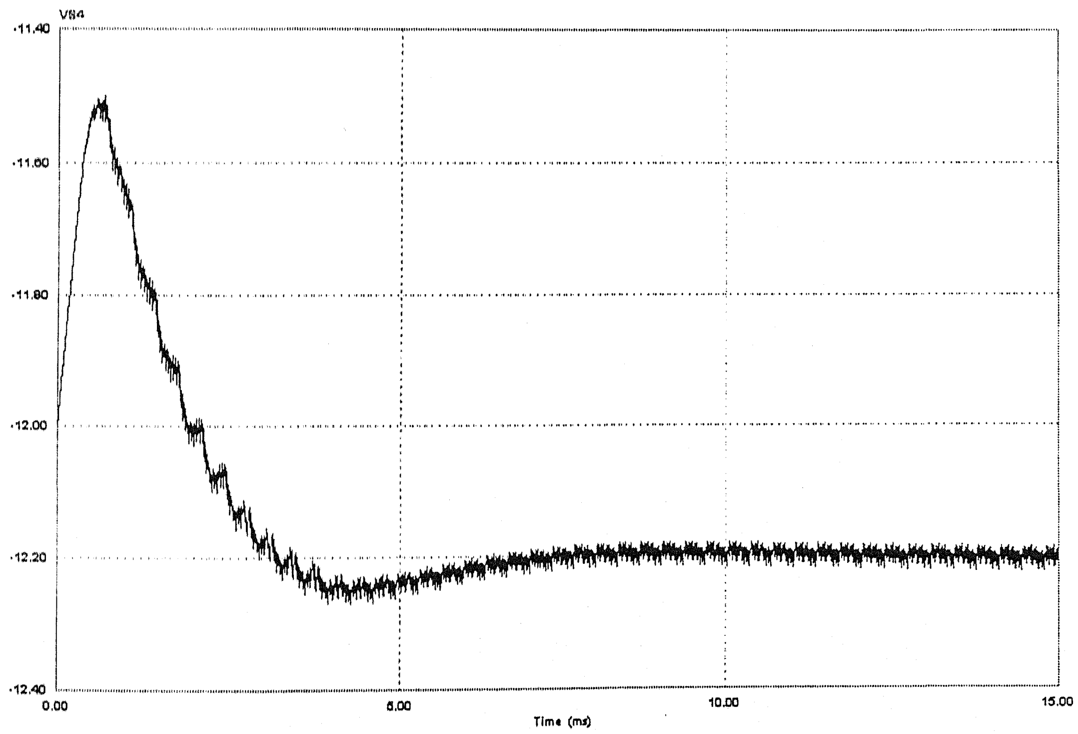

Fig 6.11 Simulated -12V output waveform for CPU

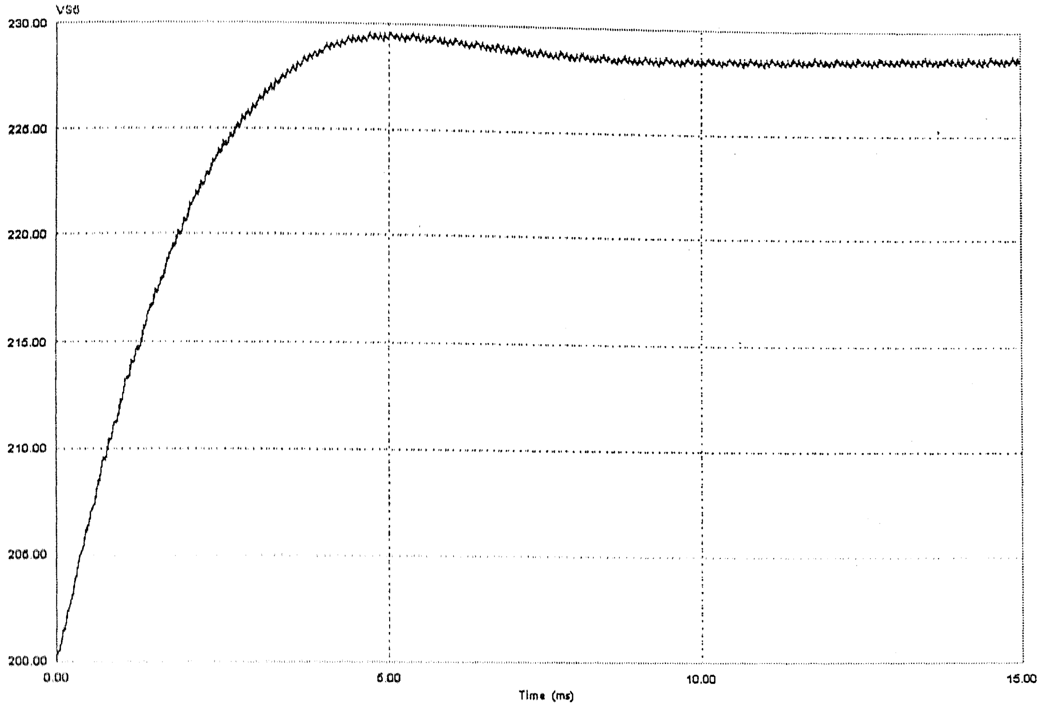

Fig 6.12 Simulated +230V output waveform for Monitor

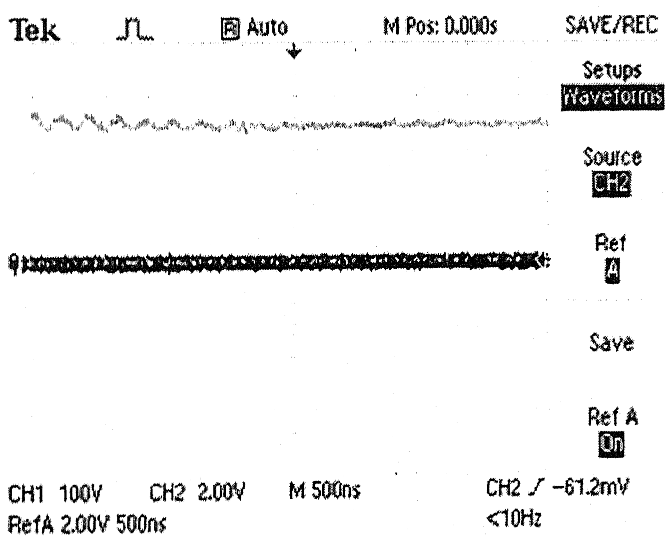

Fig 6.13 Experimental +5V output waveform for CPU

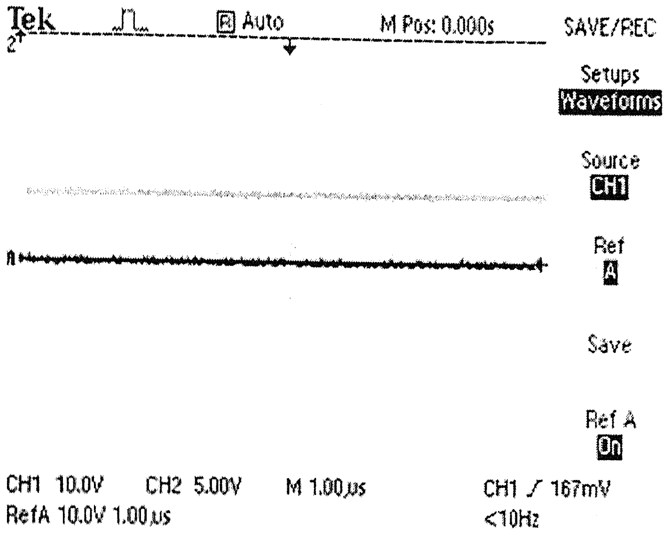

Fig 6.14 Experimental +12V output waveform for CPU

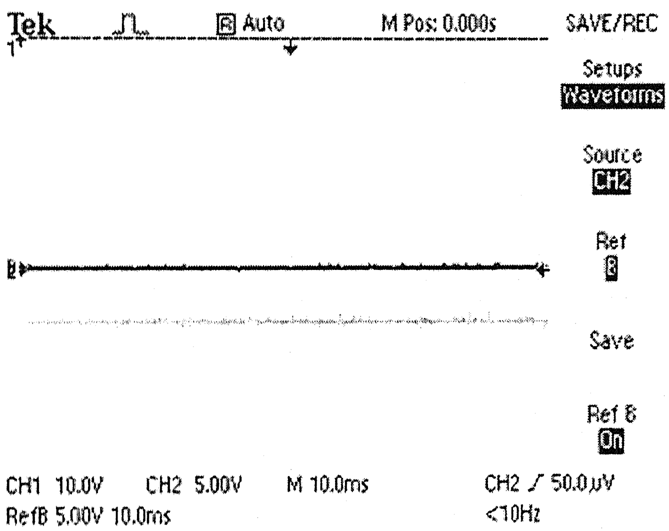

Fig 6.15 Experimental -5V output waveform for CPU

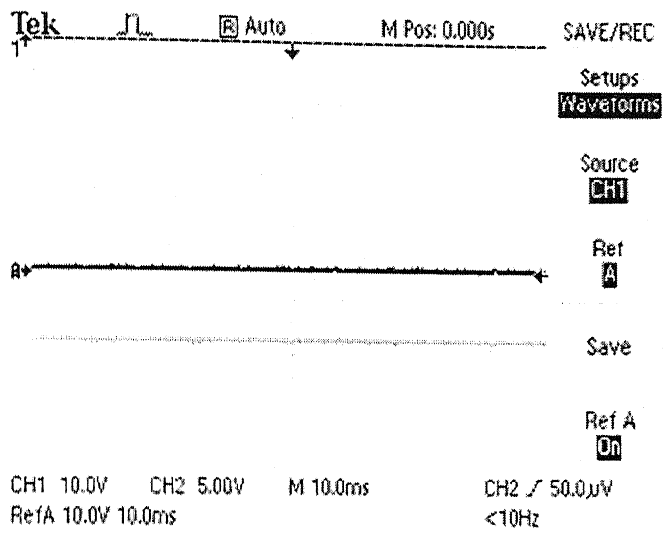

Fig 6.16 Experimental -12V output waveform for CPU

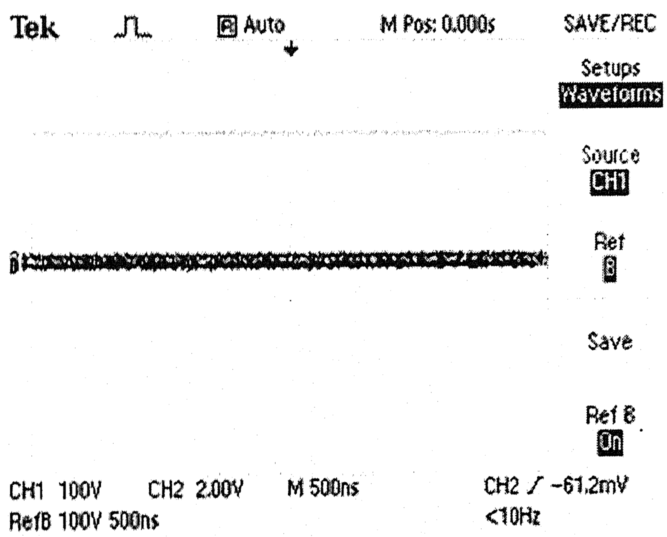

Fig 6.17 Experimental +230V output waveform for Monitor

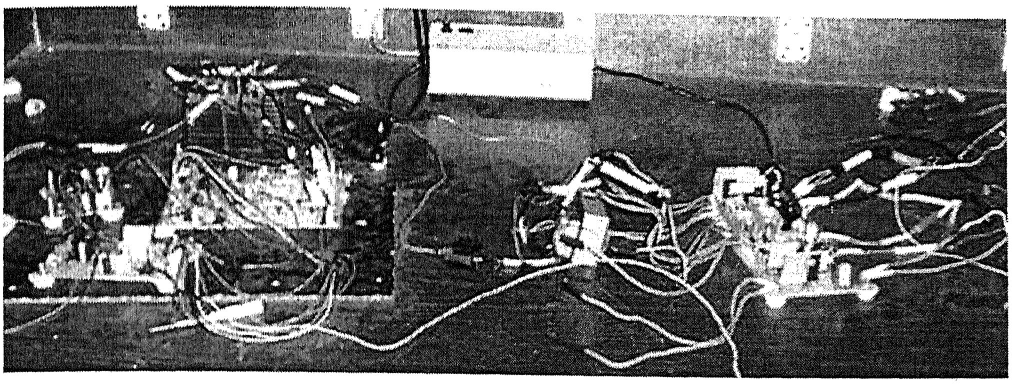

Fig 6.18 A view of experimental setup under development

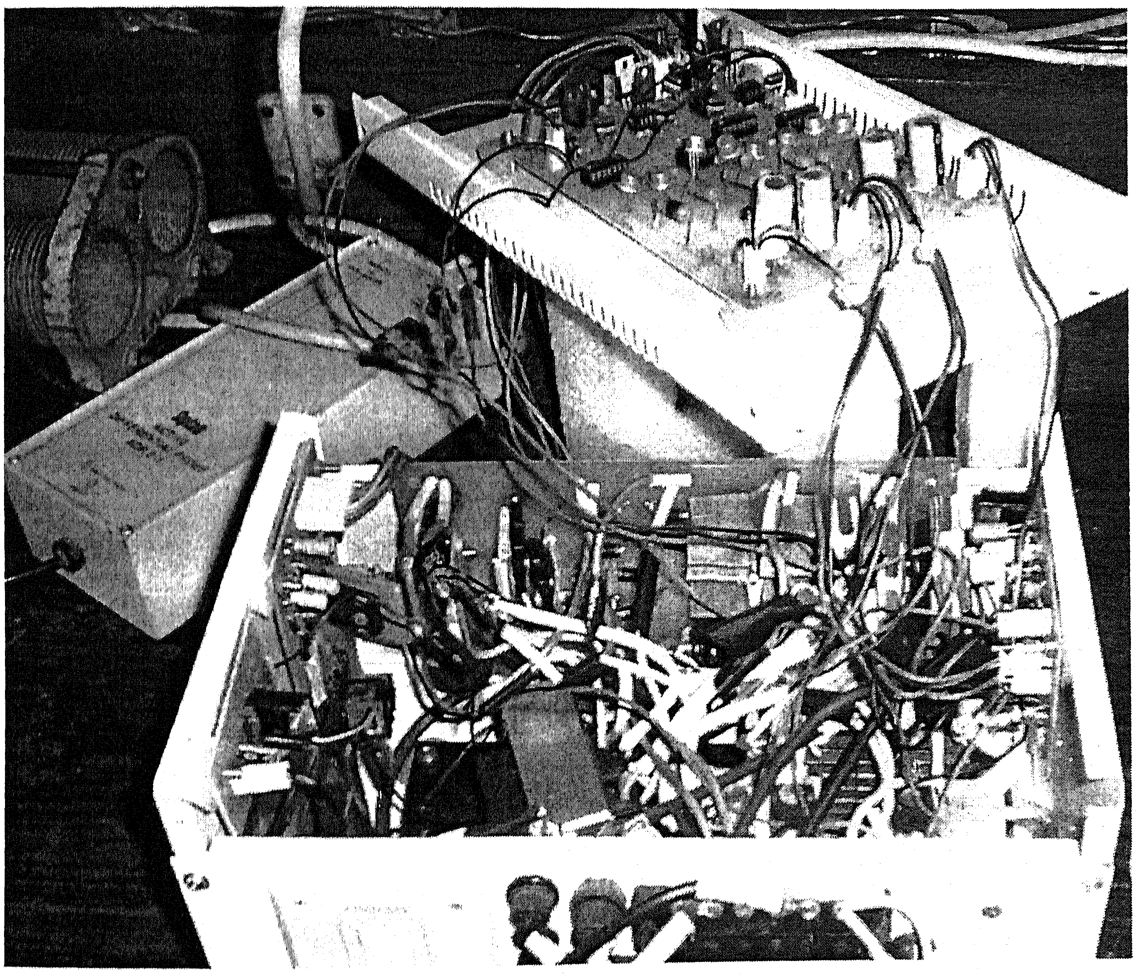

Fig 6.19 A inside view of the prototype

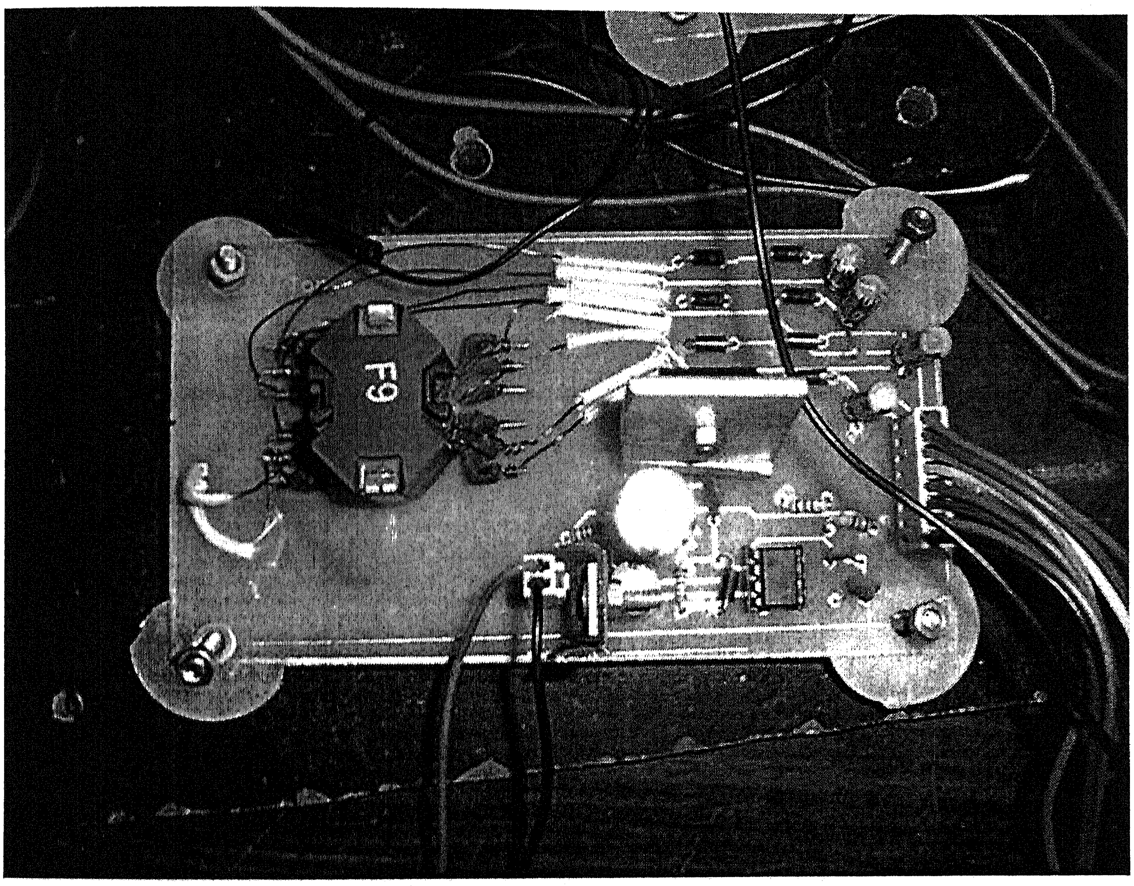

Fig 6.20 Flyback converter

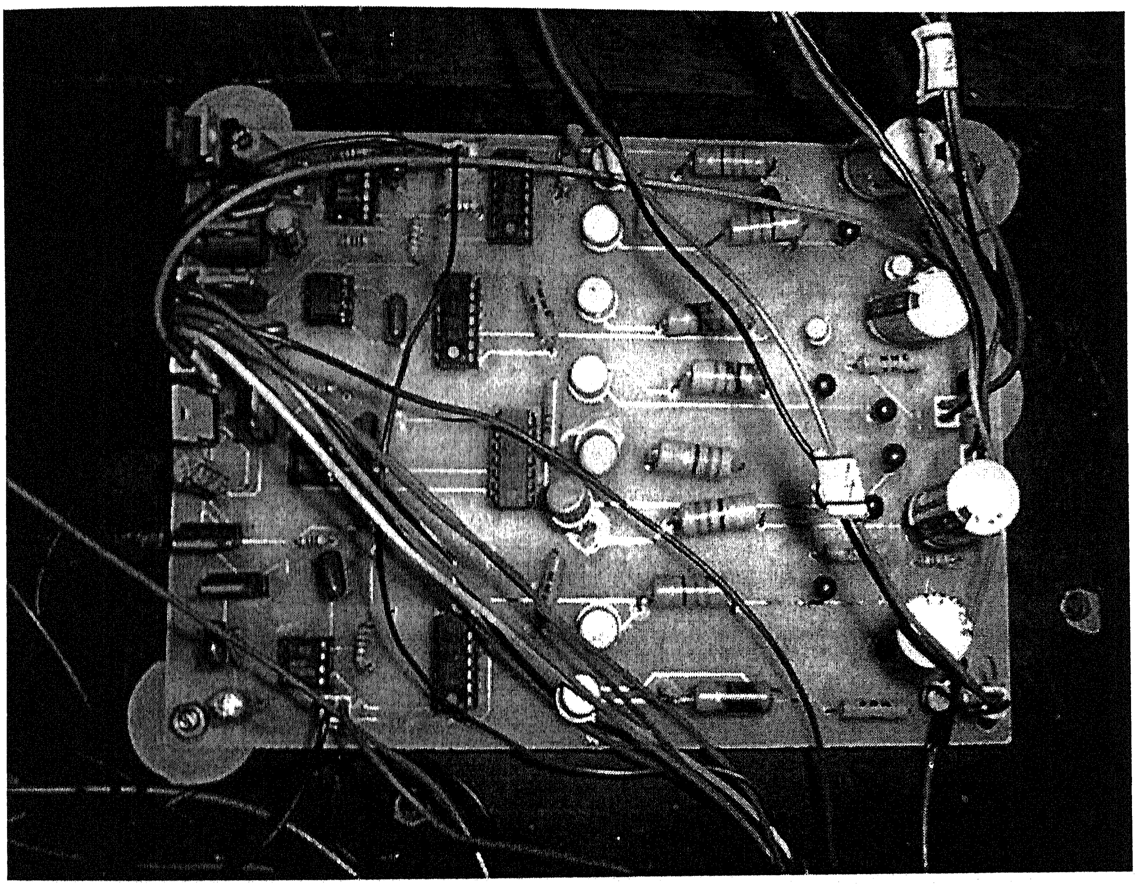

Fig 6.21 MOSFET driver circuit

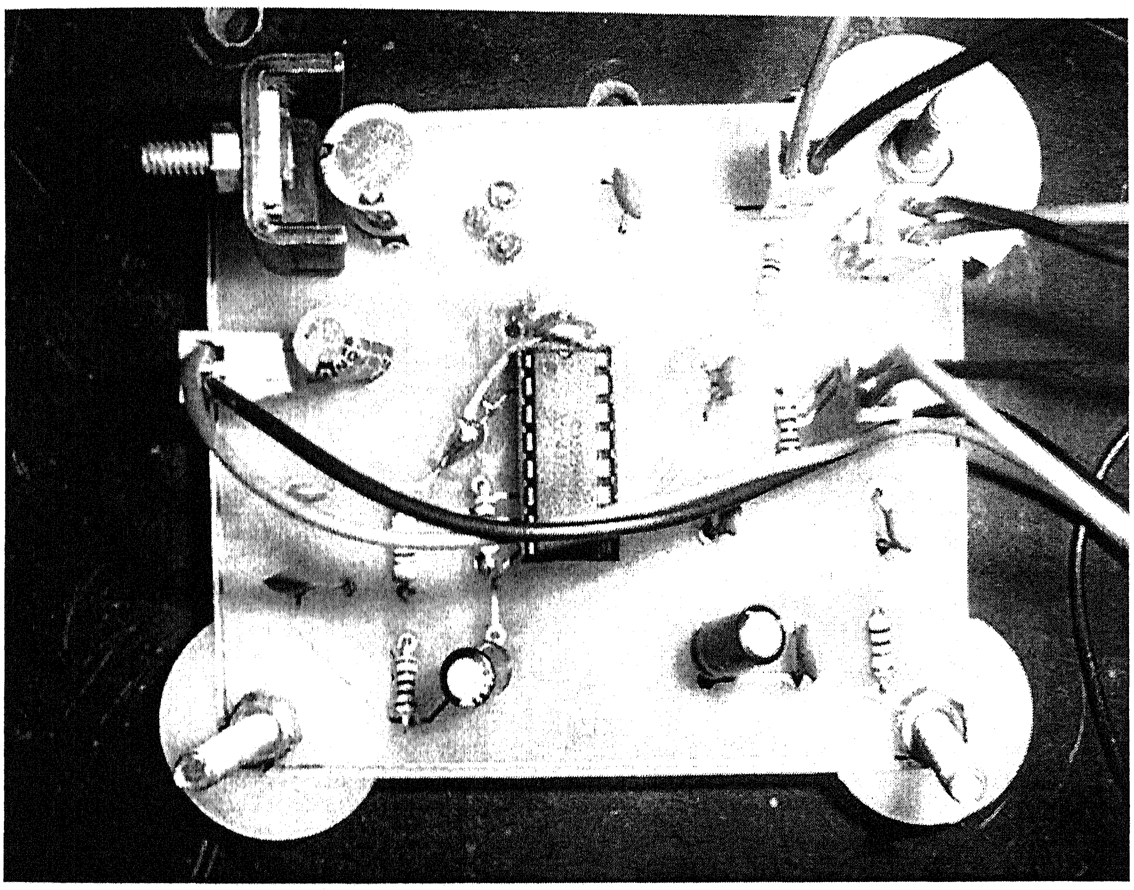

Fig 6.22 Control circuit

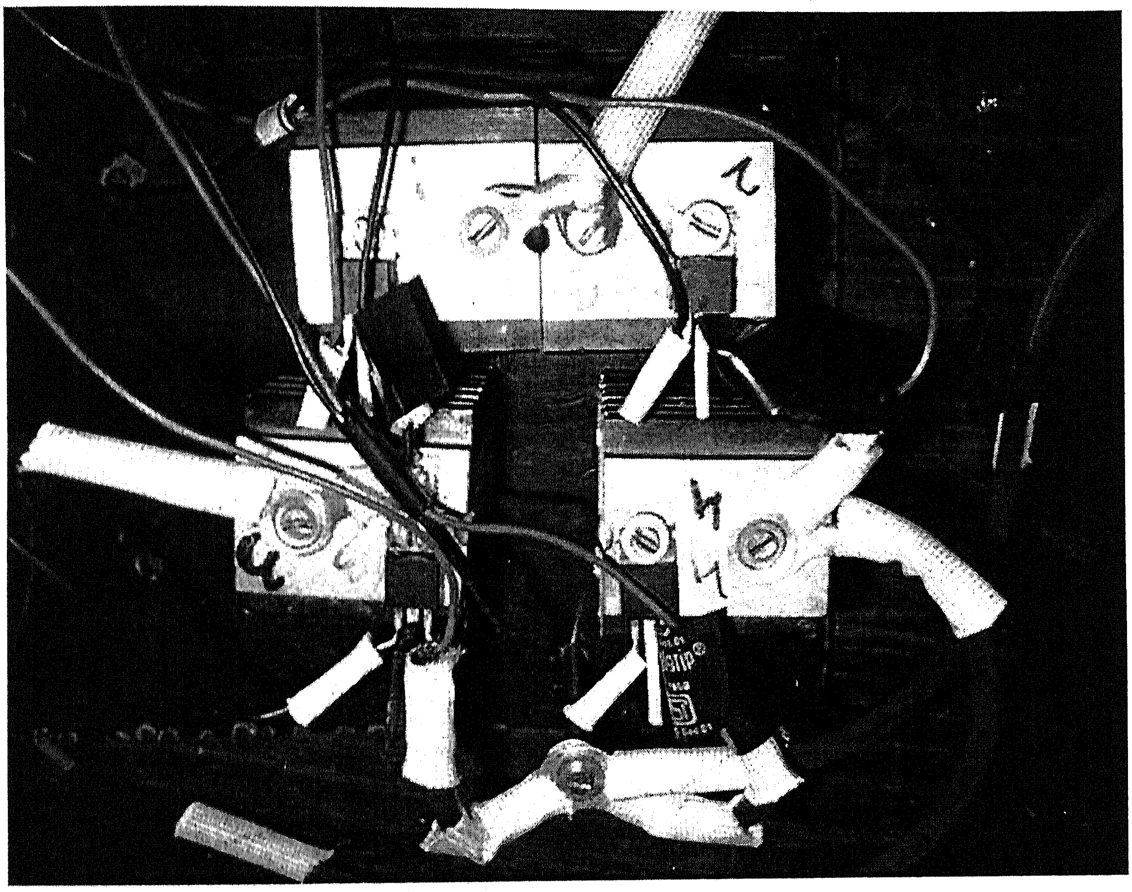

Fig 6.23 Inverter

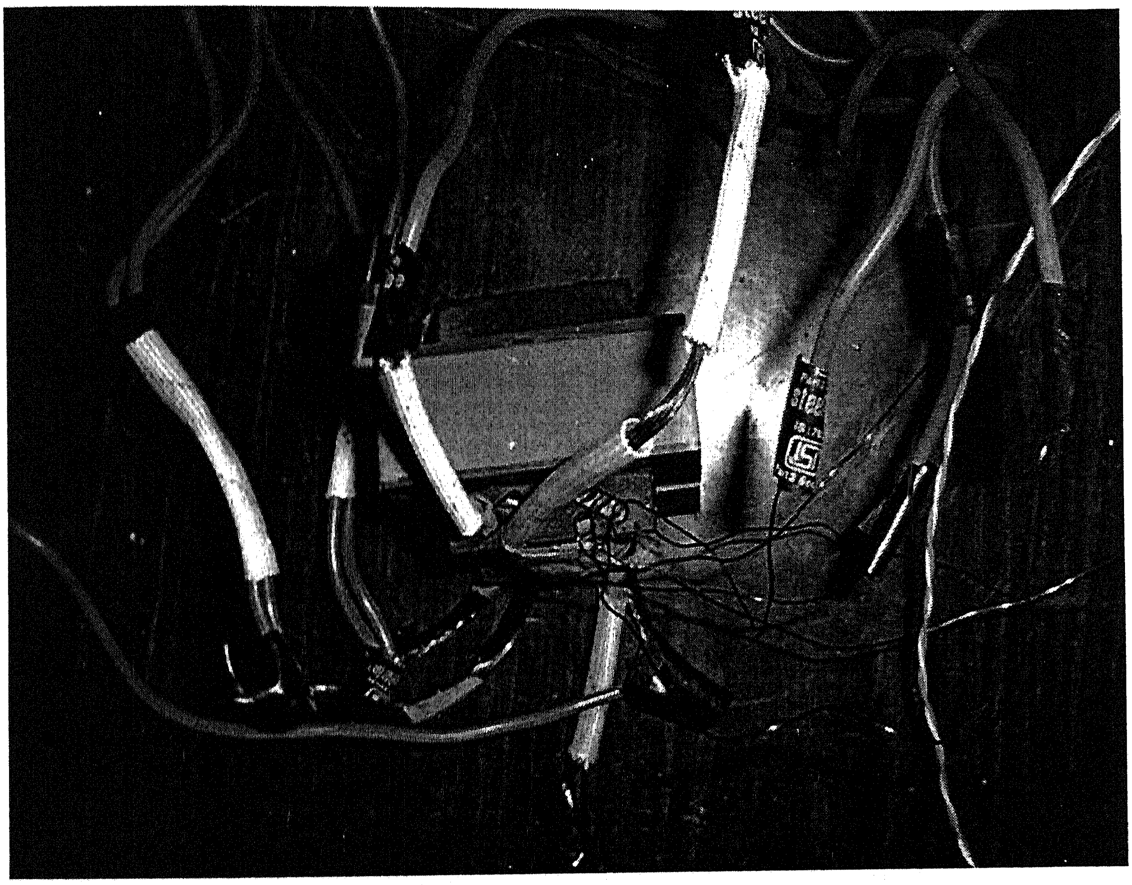

Fig 6.24 High frequency ferrite core transformer

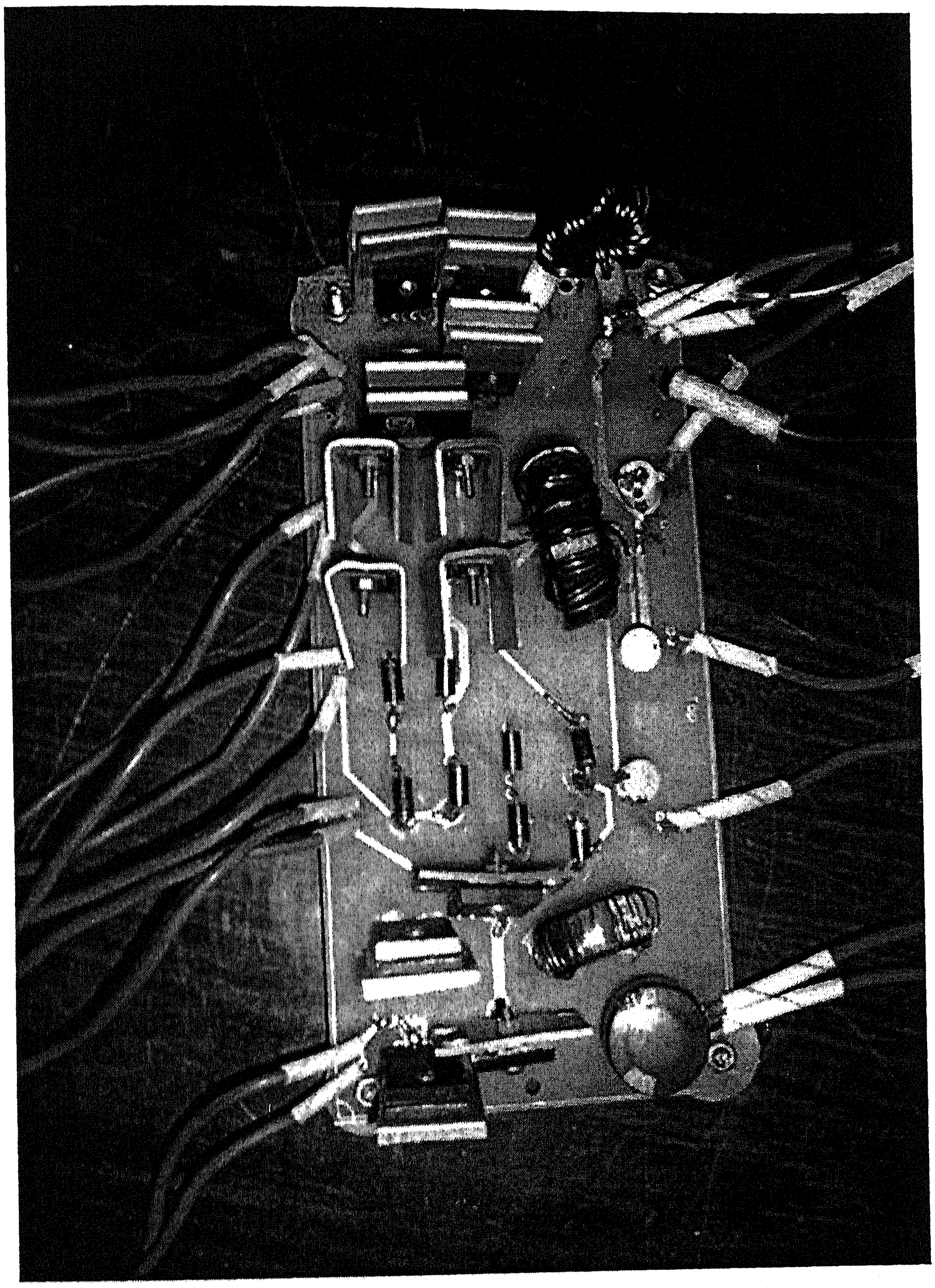

Fig 6.25 Rectifiers and filters

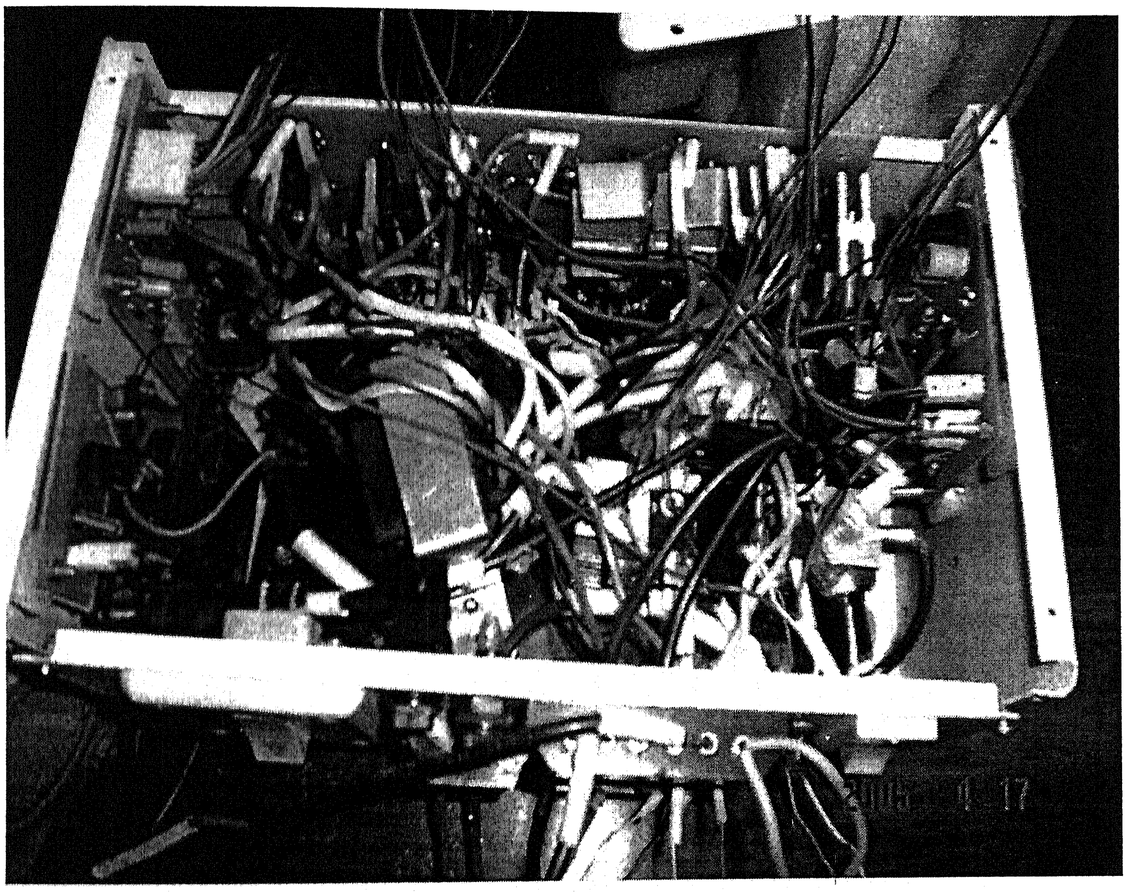

Fig 6.26 Top view of the prototype developed

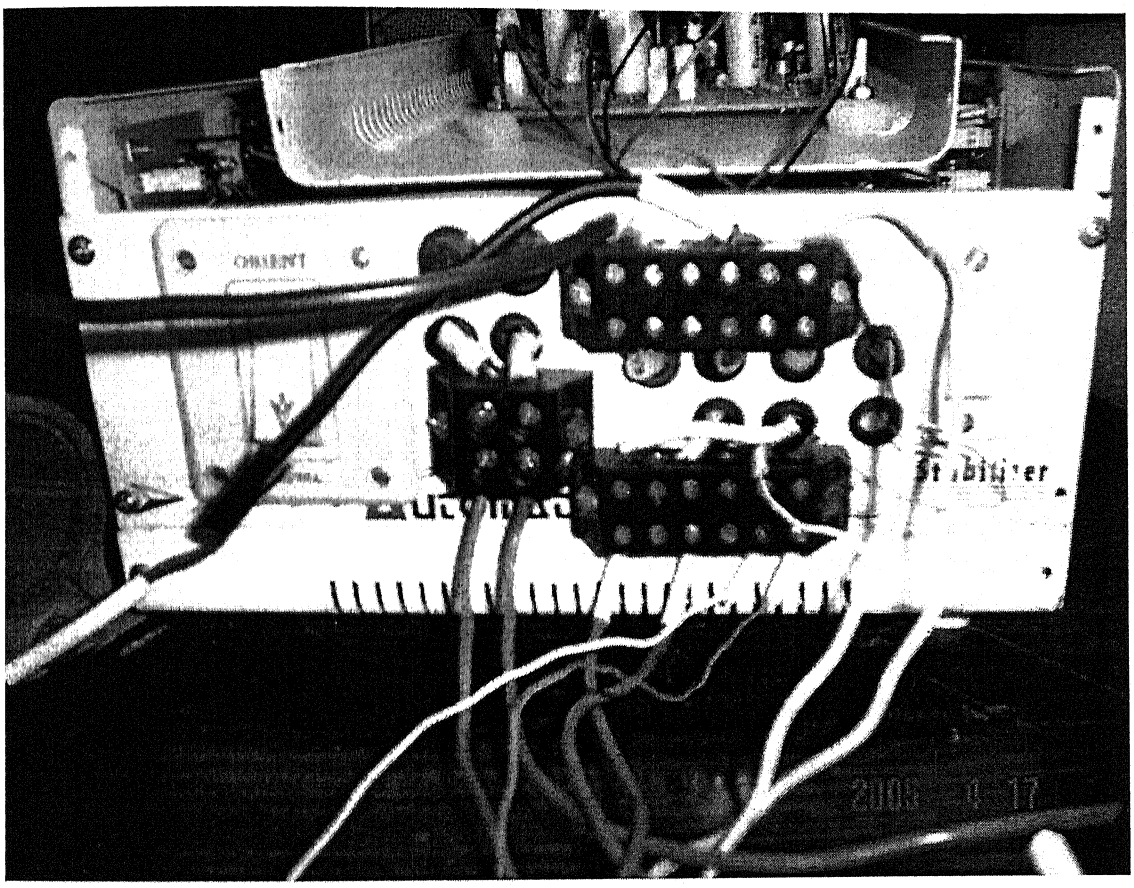

Fig 6.27 Input and output connections of the prototype

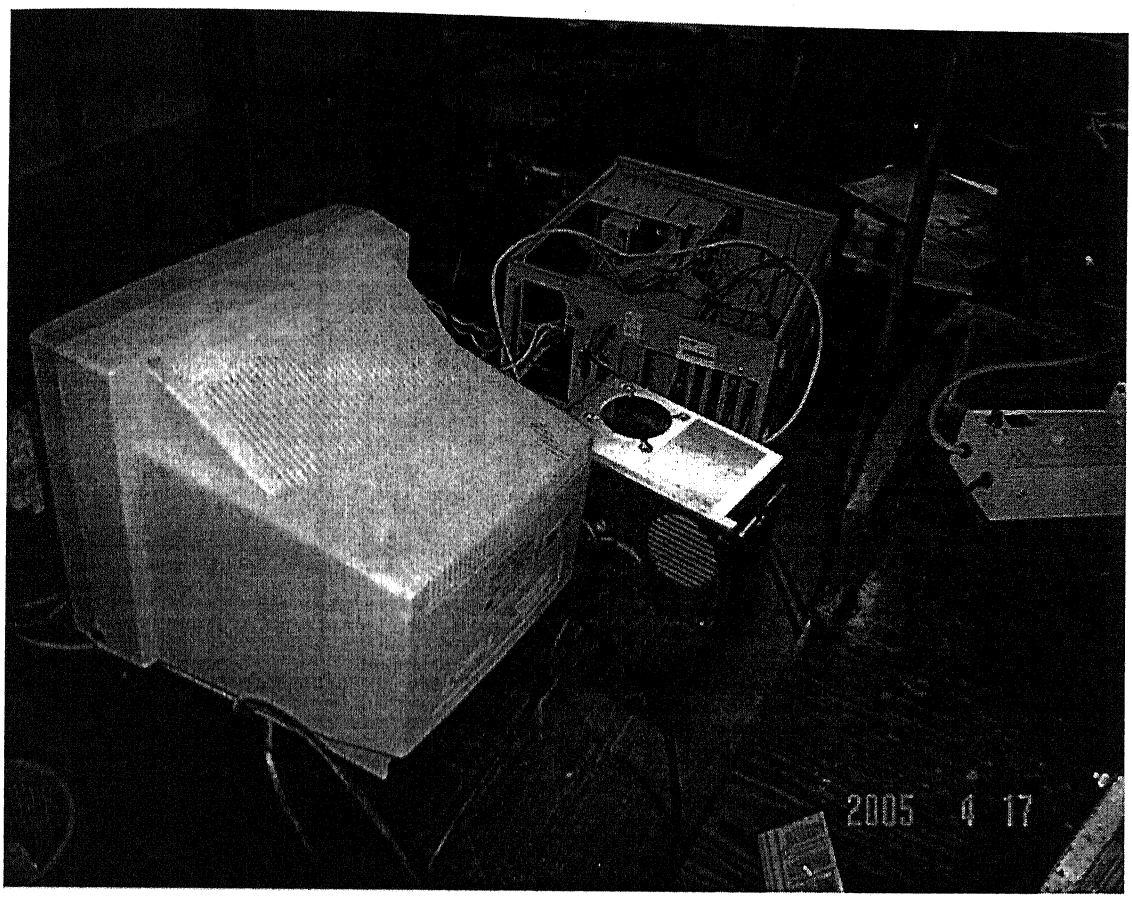

Fig 6.28 Computer system tested

6.2 Conclusions:

The objective of the work is to develop a power supply for personal computer which integrates the external UPS into the computer switching power supply to form an uninterruptible switched–mode power supply. The developed system, in principle, meets all the specifications and benchmarks, aiming at which it was started to develop. Thus, the project has been successfully accomplished.

6.3 Future Scope of Work:

Besides successful results obtained, there is scope for further improvements. The same system can be implemented using forward converter topology. The control part is too large, and can be easily made compact by using integrated modules in place of discrete devices. Soft switching techniques can be applied to increase the efficiency.

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A.1 Data Sheets

A.1.1 IRFP250N

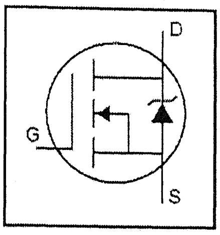
International
IOR Rectifier

PD - 94008

IRFP250N

HEXFET® Power MOSFET

- Advanced Process Technology
- Dynamic dv/dt Rating
- 175°C Operating Temperature
- Fast Switching
- Fully Avalanche Rated
- Ease of Paralleling
- Simple Drive Requirements



V_{DSS} = 200V

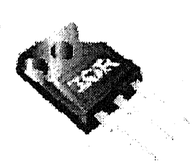
$R_{DS(on)}$ = 0.075Ω

I_D = 30A

Description

Fifth Generation HEXFETs from International Rectifier utilize advanced processing techniques to achieve extremely low on-resistance per silicon area. This benefit, combined with the fast switching speed and ruggedized device design that HEXFET Power MOSFETs are well known for, provides the designer with an extremely efficient and reliable device for use in a wide variety of applications.

The TO-247 package is preferred for commercial-industrial applications where higher power levels preclude the use of TO-220 devices. The TO-247 is similar but superior to the earlier TO-218 package because of its isolated mounting hole.



TO-247AC

Absolute Maximum Ratings

	Parameter	Max.	Units
I_D @ T_C = 25°C	Continuous Drain Current, V_{GS} @ 10V	30	A
I_D @ T_C = 100°C	Continuous Drain Current, V_{GS} @ 10V	21	
I_{DM}	Pulsed Drain Current ①	120	
P_D @ T_C = 25°C	Power Dissipation	214	W
	Linear Derating Factor	1.4	W/°C
V_{GS}	Gate-to-Source Voltage	± 20	V
E_{AS}	Single Pulse Avalanche Energy ②	315	mJ
I_{AR}	Avalanche Current ①	30	A
E_{AR}	Repetitive Avalanche Energy ①	21	mJ
dv/dt	Peak Diode Recovery dv/dt ③	8.6	V/ns
T_J T_{STG}	Operating Junction and Storage Temperature Range	-55 to +175	°C
	Soldering Temperature, for 10 seconds	300 (1.6mm from case)	
	Mounting torque, 6-32 or M3 srew	10 lbf·in (1.1N·m)	

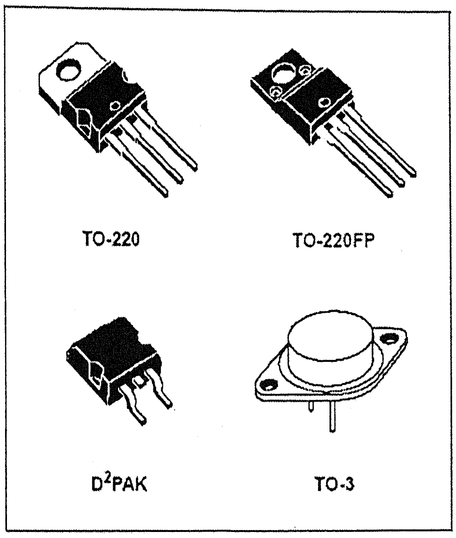
Thermal Resistance

	Parameter	Typ.	Max.	Units
$R_{θJC}$	Junction-to-Case	—	0.7	°C/W
$R_{θCS}$	Case-to-Sink, Flat, Greased Surface	0.24	—	
$R_{θJA}$	Junction-to-Ambient	—	40	

A.1.2 L7800

POSITIVE VOLTAGE REGULATORS

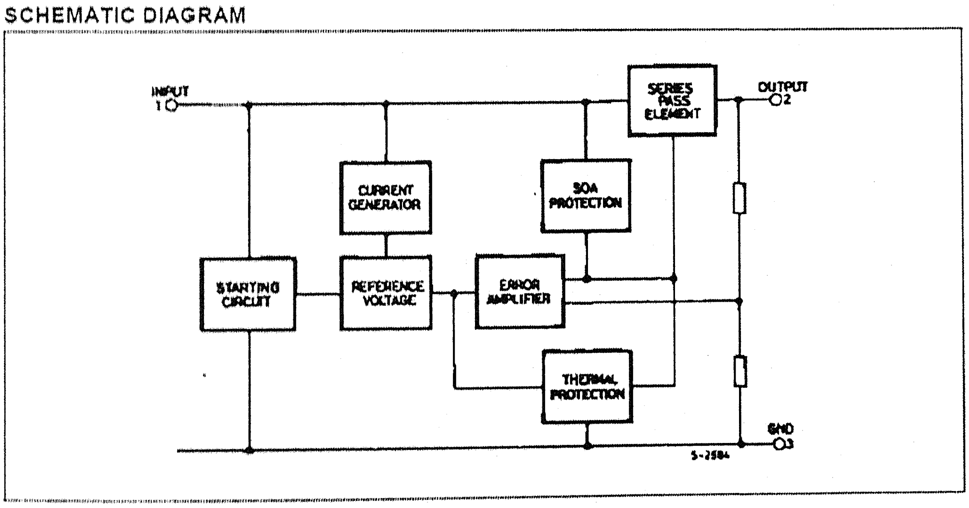
- OUTPUT CURRENT TO 1.5A
- OUTPUT VOLTAGES OF 5; 5.2; 6; 8; 8.5; 9; 12; 15; 18; 24V
- THERMAL OVERLOAD PROTECTION
- SHORT CIRCUIT PROTECTION
- OUTPUT TRANSITION SOA PROTECTION



DESCRIPTION

The L7800 series of three-terminal positive regulators is available in TO-220, TO-220FP, TO-3 and D^{2}PAK packages and several fixed output voltages, making it useful in a wide range of applications. These regulators can provide local on-card regulation, eliminating the distribution problems associated with single point regulation. Each type employs internal current limiting, thermal shut-down and safe area protection, making it essentially indestructible. If adequate heat sinking is provided, they can deliver over 1A output current. Although designed primarily as fixed voltage regulators, these devices can be used with external components to obtain adjustable voltage and currents.

SCHEMATIC DIAGRAM



ABSOLUTE MAXIMUM RATINGS

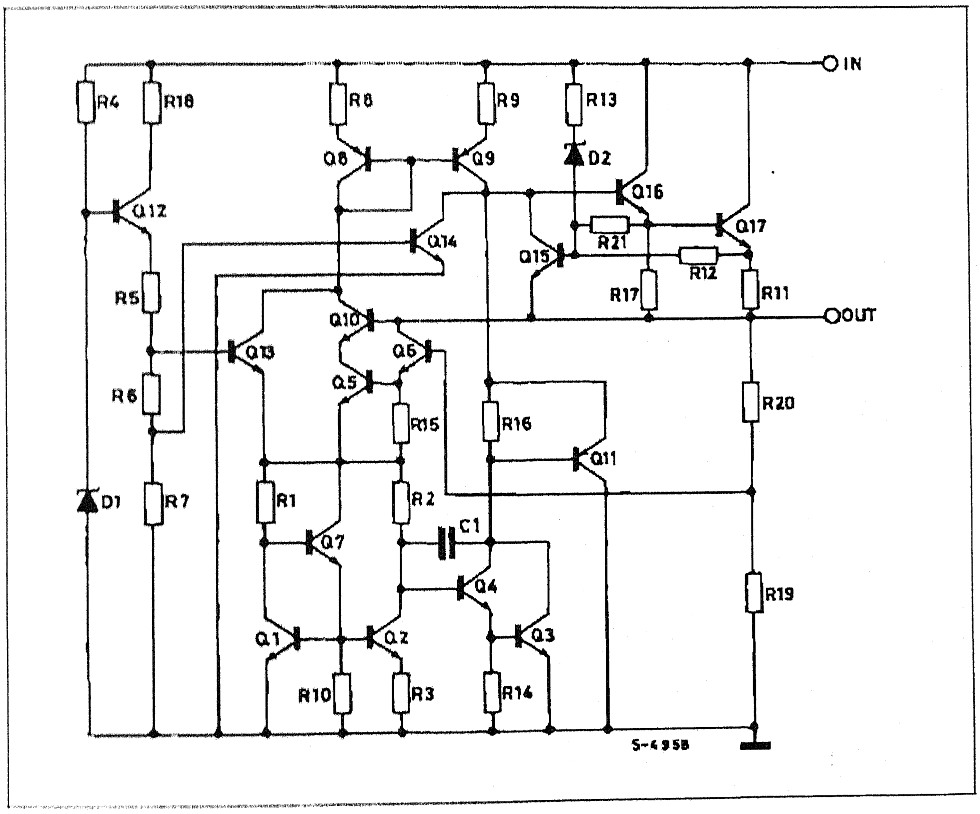
Symbol	Parameter[2]		Value	Unit
V_I	DC Input Voltage	for V_O= 5 to 18V	35	V
		for V_O= 20, 24V	40	
I_O	Output Current		Internally Limited	
P_{tot}	Power Dissipation		Internally Limited	
T_{stg}	Storage Temperature Range		-65 to 150	°C
T_{op}	Operating Junction Temperature Range	for L7800	-55 to 150	°C
		for L7800C	0 to 150	

Absolute Maximum Ratings are those values beyond which damage to the device may occur. Functional operation under these condition is not implied.

THERMAL DATA

Symbol	Parameter	D^2PAK	TO-220	TO-220FP	TO-3	Unit
$R_{thj-case}$	Thermal Resistance Junction-case Max	3	5	5	4	°C/W
$R_{thj-amb}$	Thermal Resistance Junction-ambient Max	62.5	50	60	35	°C/W

SCHEMATIC DIAGRAM



A.1.3 UC3525AN

Unitrode Products
from Texas Instruments

UC1525A/27A
UC2525A/27A
UC3525A/27A

Regulating Pulse Width Modulators

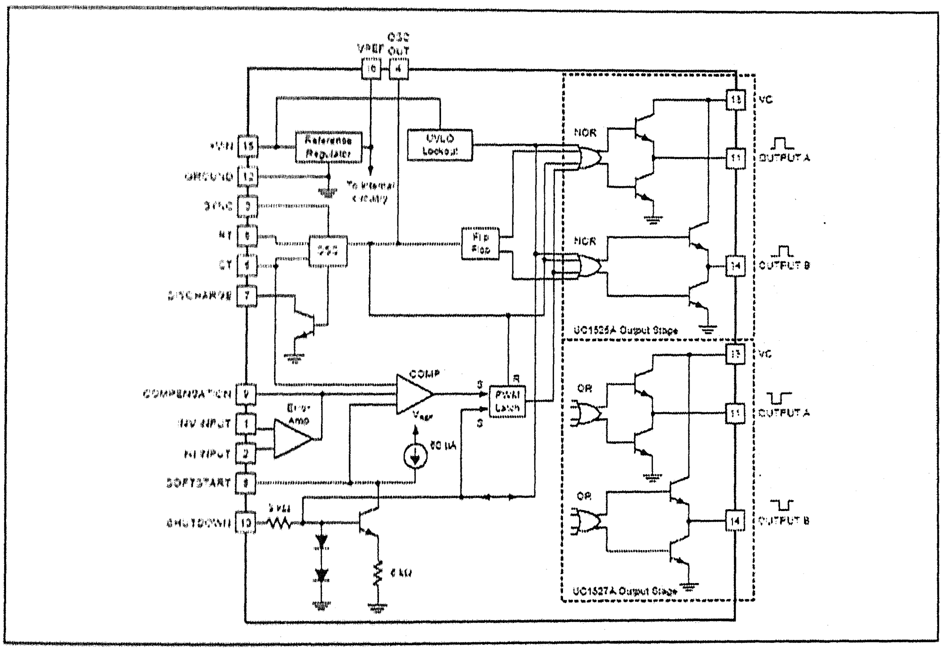
FEATURES

- 8 to 35V Operation
- 5.1V Reference Trimmed to ±1%
- 100Hz to 500kHz Oscillator Range
- Separate Oscillator Sync Terminal
- Adjustable Deadtime Control
- Internal Soft-Start
- Pulse-by-Pulse Shutdown
- Input Undervoltage Lockout with Hysteresis
- Latching PWM to Prevent Multiple Pulses
- Dual Source/Sink Output Drivers

DESCRIPTION

The UC1525A/1527A series of pulse width modulator integrated circuits are designed to offer improved performance and lowered external parts count when used in designing all types of switching power supplies. The on-chip +5.1V reference is trimmed to ±1% and the input common-mode range of the error amplifier includes the reference voltage, eliminating external resistors. A sync input to the oscillator allows multiple units to be slaved or a single unit to be synchronized to an external system clock. A single resistor between the C_T and the discharge terminals provides a wide range of dead-time adjustment. These devices also feature built-in soft-start circuitry with only an external timing capacitor required. A shutdown terminal controls both the soft-start circuitry and the output stages, providing instantaneous turn off through the PWM latch with pulsed shutdown, as well as soft-start recycle with longer shutdown commands. These functions are also controlled by an undervoltage lockout which keeps the outputs off and the soft-start capacitor discharged for sub-normal input voltages. This lockout circuitry includes approximately 500mV of hysteresis for jitter-free operation. Another feature of these PWM circuits is a latch following the comparator. Once a PWM pulse has been terminated for any reason, the outputs will remain off for the duration of the period. The latch is reset with each clock pulse. The output stages are totem-pole designs capable of sourcing or sinking in excess of 200mA. The UC1525A output stage features NOR logic, giving a LOW output for an OFF state. The UC1527A utilizes OR logic which results in a HIGH output level when OFF.

BLOCK DIAGRAM



ABSOLUTE MAXIMUM RATINGS (Note 1)

Supply Voltage, ($+V_{IN}$) . . . . . +40V
Collector Supply Voltage (V_C) . . . . . +40V
Logic Inputs . . . . . −0.3V to +5.5V
Analog Inputs . . . . . −0.3V to $+V_{IN}$
Output Current, Source or Sink 500mA
Reference Output Current 50mA
Oscillator Charging Current 5mA
Power Dissipation at T_A = +25°C (Note 2) 1000mW
Power Dissipation at T_C = +25°C (Note 2) 2000mW
Operating Junction Temperature . . . . . −55°C to +150°C
Storage Temperature Range . . . . . −65°C to +150°C
Lead Temperature (Soldering, 10 seconds) . . . . . +300°C

Note 1: Values beyond which damage may occur.
Note 2: Consult packaging Section of Databook for thermal limitations and considerations of package.

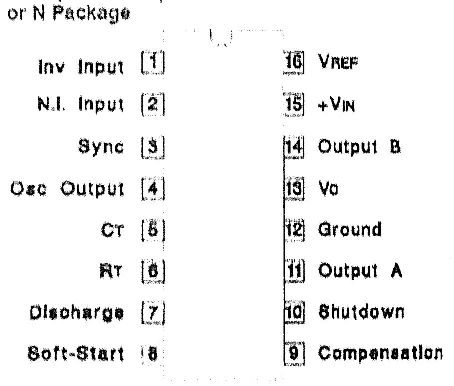
RECOMMENDED OPERATING CONDITIONS (Note 3)

Input Voltage ($+V_{IN}$) . . . . . +8V to +35V
Collector Supply Voltage (V_C) . . . . . +4.5V to +35V
Sink/Source Load Current (steady state) . . . . . 0 to 100mA
Sink/Source Load Current (peak) . . . . . 0 to 400mA
Reference Load Current . . . . . 0 to 20mA
Oscillator Frequency Range . . . . . 100Hz to 400kHz
Oscillator Timing Resistor . . . . . 2kΩ to 150kΩ
Oscillator Timing Capacitor . . . . . .001µF to .01µF
Dead Time Resistor Range . . . . . 0 to 500Ω
Operating Ambient Temperature Range
UC1525A, UC1527A . . . . . −55°C to +125°C
UC2525A, UC2527A . . . . . −25°C to +85°C
UC3525A, UC3527A . . . . . 0°C to +70°C

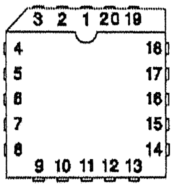
Note 3: Range over which the device is functional and parameter limits are guaranteed.

CONNECTION DIAGRAMS

DIL-16 (TOP VIEW)
J or N Package



PLCC-20, LCC-20 (TOP VIEW)
Q, L Package



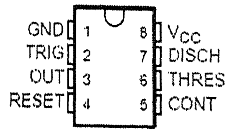
PACKAGE PIN FUNCTION	
FUNCTION	PIN
N/C	1
Inv. Input	2
N.I. Input	3
SYNC	4
OSC. output	5
N/C	6
C_T	7
R_T	8
Discharge	9
Softstart	10
N/C	11
Compensation	12
Shutdown	13
Output A	14
Ground	15
N/C	16
V_C	17
Output B	18
$+V_{IN}$	19
V_{REF}	20

A.1.4 NE555N

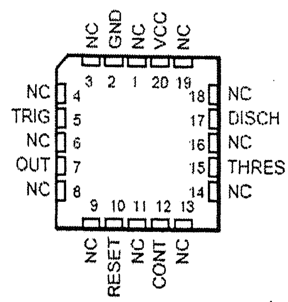
- Timing From Microseconds to Hours
- Astable or Monostable Operation
- Adjustable Duty Cycle
- TTL-Compatible Output Can Sink or Source up to 200 mA
- Functionally Interchangeable With the Signetics NE555, SA555, SE555, SE555C; Have Same Pinout

SE555C FROM TI IS NOT RECOMMENDED FOR NEW DESIGNS

D, JG, OR P PACKAGE
(TOP VIEW)



FK PACKAGE
(TOP VIEW)



NC–No internal connection

description

These devices are precision monolithic timing circuits capable of producing accurate time delays or oscillation. In the time-delay or monostable mode of operation, the timed interval is controlled by a single external resistor and capacitor network. In the astable mode of operation, the frequency and duty cycle may be independently controlled with two external resistors and a single external capacitor.

The threshold and trigger levels are normally two-thirds and one-third, respectively, of V_{CC}. These levels can be altered by use of the control voltage terminal. When the trigger input falls below the trigger level, the flip-flop is set and the output goes high. If the trigger input is above the trigger level and the threshold input is above the threshold level, the flip-flop is reset and the output is low. RESET can override all other inputs and can be used to initiate a new timing cycle. When RESET goes low, the flip-flop is reset and the output goes low. Whenever the output is low, a low-impedance path is provided between DISCH and ground.

The output circuit is capable of sinking or sourcing current up to 200 mA. Operation is specified for supplies of 5 V to 15 V. With a 5-V supply, output levels are compatible with TTL inputs.

The NE555 is characterized for operation from 0°C to 70°C. The SA555 is characterized for operation from −40°C to 85°C. The SE555 and SE555C are characterized for operation over the full military range of −55°C to 125°C.

AVAILABLE OPTIONS

T_A	PACKAGE					CHIP FORM (Y)
	V_{THRES} max V_{CC} = 15 V	SMALL OUTLINE (D)	CHIP CARRIER (FK)	CERAMIC DIP (J)	PLASTIC DIP (P)	
0°C to 70°C	11.2 V	NE555D			NE555P	NE555Y
−40°C to 85°C	11.2 V	SA555D			SA555P	
−55°C to 125°C	10.6 V 11.2 V	SE555D SE555CD	SE555FK SE555CFK	SE555JG SE555CJG	SE555P SE555CP	

The D package is available taped and reeled. Add the suffix R to the device type (e.g., NE555DR).

International
IOR Rectifier

1N5818
1N5819

SCHOTTKY RECTIFIER

1.0 Amp

Major Ratings and Characteristics

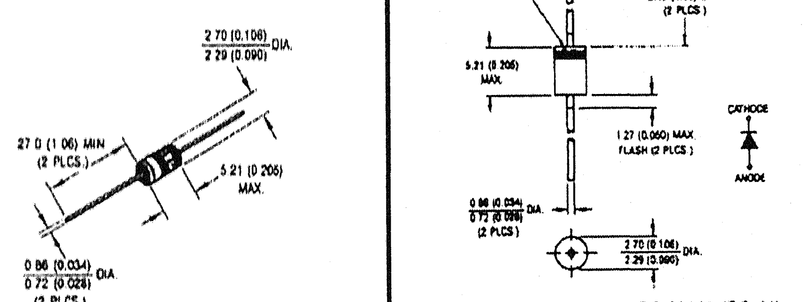
Characteristics	1N5818 1N5819	Units
$I_{F(AV)}$ Rectangular waveform	1.0	A
V_{RRM}	30/40	V
I_{FSM} @ tp = 5 µs sine	225	A
V_F @ 1 Apk, T_J = 25°C	0.55	V
T_J range	-40 to 150	°C

Description/Features

The 1N5818/ 1N5819 axial leaded Schottky rectifier has been optimized for very low forward voltage drop, with moderate leakage. Typical applications are in switching power supplies, converters, free-wheeling diodes, and reverse battery protection.

- Low profile, axial leaded outline
- High purity, high temperature epoxy encapsulation for enhanced mechanical strength and moisture resistance
- Very low forward voltage drop
- High frequency operation
- Guard ring for enhanced ruggedness and long term reliability

CASE STYLE AND DIMENSIONS
Device Marking: 1N581X



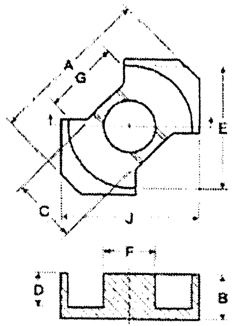
Conform to JEDEC Outline DO-204AL (DO-41)
Dimensions in millimeters and inches

A.1.6 RM10 Core

28mm X 19mm (RM 10)

DIMENSIONS

	Inches	mm		Inches	mm
A	1.122 max.	28.5 max.	2D	.500 ± .012	12.7 ± .3
B	.366 ± .002	9.3 ± .05	E	.862 ± .018	21.85 ± .45
2B	.732 ± .004	18.6 ± .1	F	.421 ± .008	10.7 ± .2
C	.520 ± .010	13.2 ± .25	G	.450 nom.	11.4 nom.
D	.250 ± .006	6.4 ± .15	J	.951 ± .022	24.16 ± .55



MAGNETIC DATA

MAGNETIC PATH LENGTH (cm)	(With Hole) 4.17	(No Hole) 4.40
EFFECTIVE AREA (cm²)	0.83	0.98
VOLUME (cm³)	3.46	4.31

CORE WEIGHT (grams per set)	(With Hole) 20	(No Hole) 23
Wa Ac ‡ (No Hole) (cm⁴)	.441	

‡ Product of window area & core area. 1 sec standard bobbin.

Note: Minimum core area .618 cm² with hole — Minimum core area .90 cm² without hole

A_L VALUES FOR UNGAPPED CORES (No Center Hole)
For A_L with hole, contact Sales Dept.

CORE NO	A_L (mH/1000T)
NK-42819-UG	2130 min.
NR-42819-UG	3035 min.
NP-42819-UG	3300 min.
NF-42819-UG	5500 ± 25%

CORE NO	A_L (mH/1000T)
NJ-42819-UG	7490 min.
NW-42819-UG	11,200 min. (B = 5G) 20,900 Ref. nom.* (B = 178G)

FOR PREFERRED PARTS, SEE INSIDE BACK COVER *@ 1 kHZ, 100 Turns, 0.5 mA

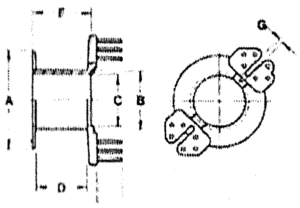
This part is available with .219" center hole. To order, substitute "R" for "N" in part number E.g., RP-42819-UG.

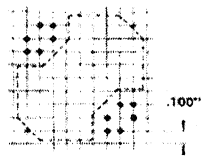
Also available as low profile.
2D = .149" (3.8mm)
2B = .374" (9.5 mm).
Part no. **-42809-UG.
Add "R" or "N" and material code at **.

Any practical gap is available.
See pages 1.6 and 1.7.

BOBBINS

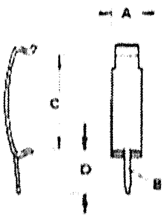
Material: Thermoset phenolic (UL 94 V-0 rated)
Terminals: Tin plated phosphor bronze, .024" ϕ





* Bobbin
*Clamp

PART NUMBER	DIMENSIONS IN INCHES							Nominal Winding Area		Average Length of Turn
	A MAX.	B MAX.	C MIN.	D NOM.	E MAX.	F MIN.	G NOM.	in²	Cm²	ft
PC-B2819-L1	.827	.492	.437	.417	.480	.205	.051	.07	.452	.172



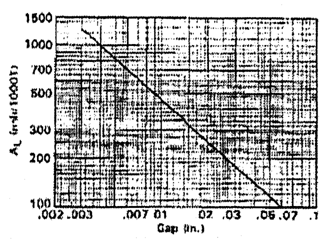
Material: Spring Steel .018" thick

(All dimensions in inches - nominal)

PART NUMBER	A	B	C	D
C2819-16*	.177	.029 x .016	.612	.199

**Two required per core set*

A_L vs Gap



6N137

DEGITAL LOGIC ISOLATION

TELE-COMMUNICATION

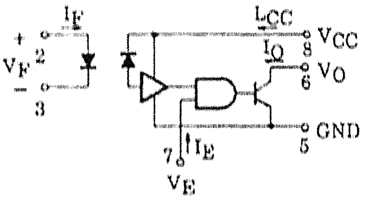
ANALOG DATA EQUIPMENT CONTROL

The TOSHIBA 6N137 consist of a high emitting diode and a one chip photo IC. This unit is 8-lead DIP package.

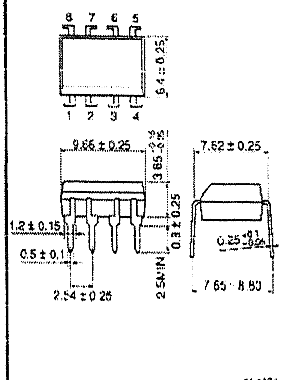
- LSTTL/TTL Compatible : 5V Supply
- Ultra High Speed : 10MBd
- Guaranteed Performance Over Temperature : 0°C to 70°C
- High Isolation Voltage : 2500Vrms Min.
- UL Recognized : UL1577, File No. E67349

TRUTH TABLE

INPUT	ENABLE	OUTPUT
H	H	L
L	H	H
H	L	H
L	L	H



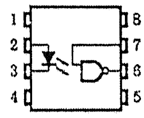
Unit in mm



TOSHIBA 11-10C4

Weight : 0.54g

PIN CONFIGURATIONS (Top view)



1 : N.C.
2 : ANODE
3 : CATHODE
4 : N.C.
5 : GND
6 : OUTPUT (OPEN COLLECTOR)
7 : ENABLE
8 : V_{CC}

A.1.8 MM74C901N

MM74C901 • MM74C902
Hex Inverting TTL Buffer • Hex Non-Inverting TTL Buffer

General Description

The MM74C901 and MM74C902 hex buffers employ complementary MOS to achieve wide supply operating range, low power consumption, and high noise immunity. These buffers provide direct interface from PMOS into CMOS or TTL and direct interface from CMOS to TTL or CMOS operating at a reduced V_{CC} supply

Features

- Wide supply voltage range: 3.0V to 15V
- Guaranteed noise margin: 1.0V
- High noise immunity: 0.45 V_{CC} (typ.)
- TTL compatibility: Fan out of 2 driving standard TTL

Ordering Code:

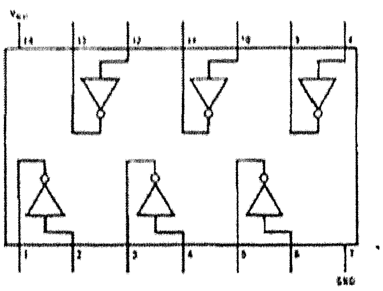
Order Number	Package Number	Package Description
MM74C901M	M14A	14-Lead Small Outline Integrated Circuit (SOIC), JEDEC MS-120, 0.150" Narrow
MM74C901N	N14A	14-Lead Plastic Dual-In-Line Package (PDIP), JEDEC MS-011, 0.300" Wide
MM74C902M	M14A	14-Lead Small Outline Integrated Circuit (SOIC), JEDEC MS-120, 0.150" Narrow
MM74C902N	N14A	14-Lead Plastic Dual-In-Line Package (PDIP), JEDEC MS-011, 0.300" Wide

Devices also available in Tape and Reel. Specify by appending the suffix letter "X" to the ordering code.

Connection Diagrams

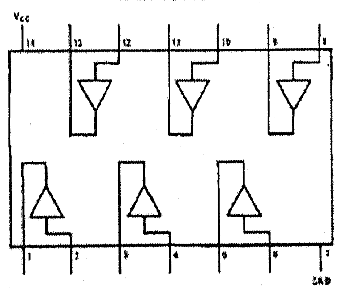
Pin Assignments for DIP and SOIC

MM74C901



Top View

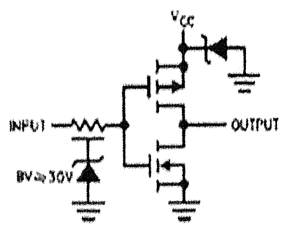
MM74C902



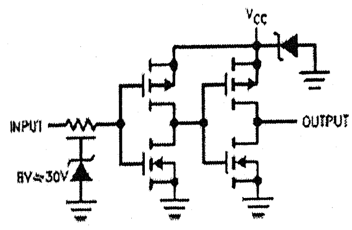
Top View

Logic Diagrams

MM74C901
CMOS to TTL Inverting Buffer



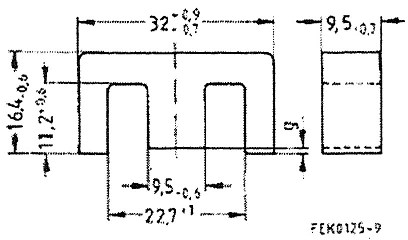
MM74C902
CMOS to TTL Buffer



A.1.9 E 32/16/9 Core

E 32/16/9 (EF 32)
Core B66229

- In accordance with IEC 61246
- E cores are supplied as single units



Magnetic characteristics (per set)

$\Sigma l/A$ = 0,89 mm^{-1}
l_e = 74 mm
A_e = 83 mm^2
A_{min} = 81,4 mm^2
V_e = 6 140 mm^3

Approx. weight 30 g/set

Ungapped

Material	A_L value nH	μ_e	A_{L1min} nH	P_V W/set	Ordering code
N30	3800 + 30/– 20 %	2690			B66229-G-X130
N27	2100 + 30/– 20 %	1480	1770	1,10 (200 mT, 25 kHz, 100 °C)	B66229-G-X127
N67	2250 + 30/– 20 %	1590	1770	3,75 (200 mT, 100 kHz, 100 °C)	B66229-G-X167

Gapped

Material	g mm	A_L value approx. nH	μ_e	Ordering code ** = 27 (N27) = 67 (N67)
N27,	0,50 ± 0,05	244	172	B66229-G500-X1**
N67	1,00 ± 0,05	145	103	B66229-G1000-X1**

The A_L value in the table applies to a core set comprising one ungapped core (dimension g = 0) and one gapped core (dimension g > 0).

Calculation factors (see page 423 for formulas)

Material	Relationship between air gap – A_L value		Calculation of saturation current			
	K1 (25 °C)	*K2* (25 °C)	*K3* (25 °C)	*K4* (25 °C)	*K3* (100 °C)	*K4* (100 °C)
N27	145	– 0,748	212	– 0,847	196	– 0,865
N67	145	– 0,748	204	– 0,820	197	– 0,881

Validity range: *K1*, *K2*: 0,10 mm < s < 2,50 mm
K3, *K4*: 70 nH < A_L < 710 nH

Coil former

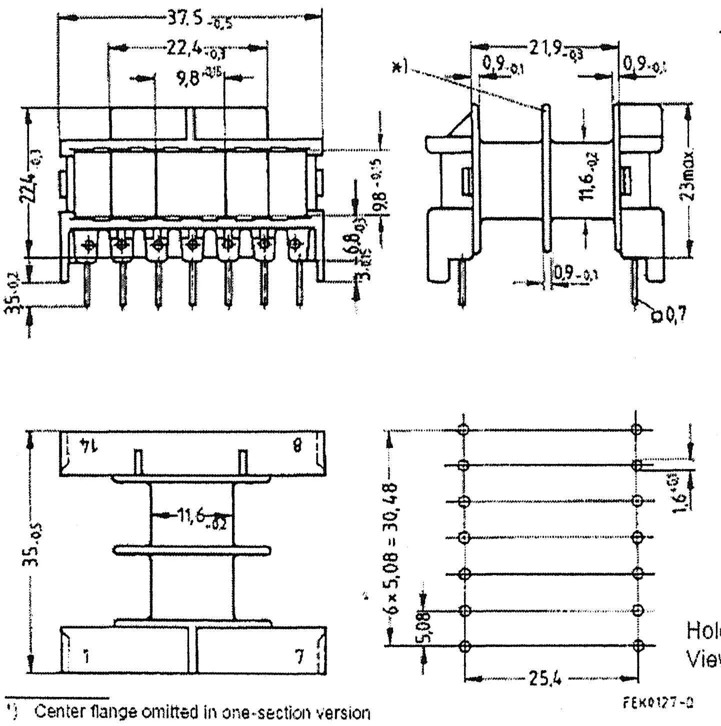
Material: GFR polyterephthalate (UL 94 V-0, insulation class to IEC 60085:
F ≙ max. operating temperature 155 °C), color code black
Solderability: to IEC 60068-2-20, test Ta, method 1 (aging 3): 235 °C, 2 s
Resistance to soldering heat: to IEC 60068-2-20, test Tb, method 1B: 350 °C, 3,5 s
Winding: see page 159
Squared pins

Yoke

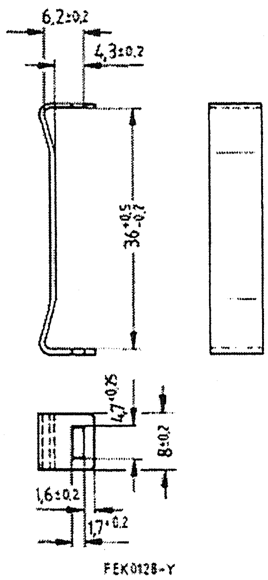
Material: Stainless spring steel (0,4 mm)

Coil former					Ordering code
Sections	A_N mm²	l_N mm	A_R value µΩ	Pins	
1	108,50	64,4	20,42	14	B66230-A1114-T1
2	103,64	64,4	21,38	14	B66230-A1114-T2
Yoke (ordering code per piece, 2 are required)					B66230-A2010

Coil former



Yoke



Hole arrangement
View in mounting direction

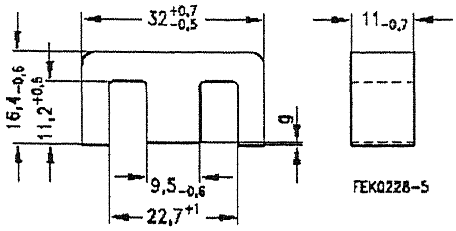
*) Center flange omitted in one-section version

● E cores are supplied as single units

Magnetic characteristics (per set)

$\Sigma l/A$ = 0,76 mm^{-1}
l_e = 74 mm
A_e = 97 mm^2
A_{min} = 95 mm^2
V_e = 7 187 mm^3

Approx. weight 37 g/set



Ungapped

Material	A_L value nH	μ_e	A_{L1min} nH	P_V W/set	Ordering code
N67	2800 + 30/– 20 %	1690	2050	4,65 (200 mT, 100 kHz, 100 °C)	B66233-G-X167

Calculation factors (see page 423 for formulas)

Material	Relationship between air gap – A_L value		Calculation of saturation current			
	K1 (25 °C)	*K2* (25 °C)	*K3* (25 °C)	*K4* (25 °C)	*K3* (100 °C)	*K4* (100 °C)
N67	165	– 0,711	239	– 0,820	231	– 0,881

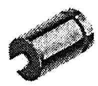
Validity range: *K1*, *K2*: 0,10 mm < s < 2,50 mm
K3, *K4*: 90 nH < A_L < 800 nH

A.1.10 1N5822

1N5820 - 1N5822

Features

- 3.0 ampere operation at T_A = 95°C with no thermal runaway.
- For use in low voltage, high frequency inverters free wheeling, and polarity protection applications.



DO-201AD
COLOR BAND DENOTES CATHODE

Schottky Rectifiers

Absolute Maximum Ratings* T_A = 25°C unless otherwise noted

Symbol	Parameter	Value			Units
		1N5820	1N5821	1N5822	
V_{RRM}	Maximum Repetitive Reverse Voltage	20	30	40	V
$I_{F(AV)}$	Average Rectified Forward Current 3/8 " lead length @ T_A = 95°C	3.0			A
I_{FSM}	Non-repetitive Peak Forward Surge Current 8.3 ms Single Half-Sine-Wave	80			A
T_{stg}	Storage Temperature Range	-65 to +125			°C
T_J	Operating Junction Temperature	-65 to +125			°C

*These ratings are limiting values above which the serviceability of any semiconductor device may be impaired.

Thermal Characteristics

Symbol	Parameter	Value	Units
P_D	Power Dissipation	3.6	W
$R_{\theta JA}$	Thermal Resistance, Junction to Ambient	28	°C/W

Electrical Characteristics T_A = 25°C unless otherwise noted

Symbol	Parameter	Device			Units
		1N5820	1N5821	1N5822	
V_F	Forward Voltage @ 3.0 A @ 9.4 A	475 850	500 900	525 950	mV mV
I_R	Reverse Current @ rated V_R T_A = 25°C T_A = 100°C	0.5 20			mA mA
C_T	Total Capacitance V_R = 4.0 V, f = 1.0 MHz	190			pF

A.1.11 PBYR2045CT

Philips Semiconductors | Product specification

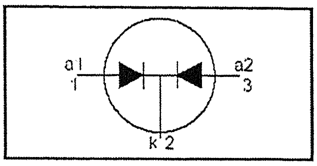
Rectifier diodes Schottky barrier

PBYR2045CT, PBYR2045CTB series

FEATURES

- Low forward volt drop
- Fast switching
- Reverse surge capability
- High thermal cycling performance
- Low thermal resistance

SYMBOL



QUICK REFERENCE DATA

V_R = 40 V/ 45 V

$I_{O(AV)}$ = 20 A

$V_F \le 0.57$ V

GENERAL DESCRIPTION

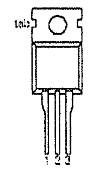
Dual, common cathode schottky rectifier diodes in a conventional leaded plastic package and a surface mounting plastic package. Intended for use as output rectifiers in low voltage, high frequency switched mode power supplies.

The PBYR2045CT series is supplied in the SOT78 conventional leaded package.
The PBYR2045CTB series is supplied in the SOT404 surface mounting package.

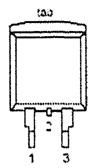
PINNING

PIN	DESCRIPTION
1	anode 1 (a)
2	cathode (k) [1]
3	anode 2 (a)
tab	cathode (k)

SOT78 (TO220AB)



SOT404



LIMITING VALUES

Limiting values in accordance with the Absolute Maximum System (IEC 134)

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.		UNIT
		PBYR20 PBYR20		40CT 40CTB	45CT 45CTB	
V_{RRM}	Peak repetitive reverse voltage		-	40	45	V
V_{RWM}	Working peak reverse voltage		-	40	45	V
V_R	Continuous reverse voltage	$T_{mb} \le 106$ °C	-	40	45	V
$I_{O(AV)}$	Average rectified forward current (both diodes conducting)	square wave; $\delta = 0.5$; $T_{mb} \le 128$ °C	-	20		A
I_{FRM}	Repetitive peak forward current per diode	square wave; $\delta = 0.5$; $T_{mb} \le 128$ °C	-	20		A
I_{FSM}	Non-repetitive peak forward current per diode	t = 10 ms t = 8.3 ms sinusoidal; T_j = 125 °C prior to surge; with reapplied $V_{RRM(max)}$	- -	135 150		A A
I_{RRM}	Peak repetitive reverse surge current per diode	pulse width and repetition rate limited by $T_{j\,max}$	-	1		A
T_j	Operating junction temperature		-	150		°C
T_{stg}	Storage temperature		- 65	175		°C

1. It is not possible to make connection to pin 2 of the SOT404 pckage.

A.1.12 RM25HG

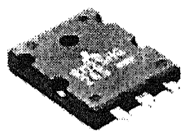
MITSUBISHI FAST RECOVERY DIODE MODULES

RM25HG-24S

HIGH SPEED SWITCHING USE

NON-INSULATED TYPE

RM25HG-24S



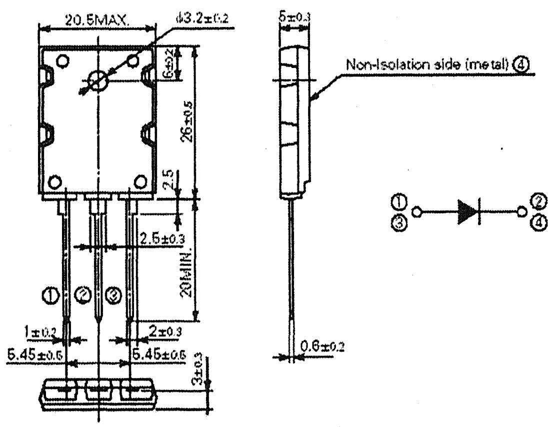
- I_{DC} DC current 25A
- V_{RRM} Repetitive peak reverse voltage 1200V
- t_{rr} Reverse recovery time 0.3μs
- ONE ARM
- Non-Insulated Type

APPLICATION

For snubber circuit (IPM or IGBT module)

OUTLINE DRAWING & CIRCUIT DIAGRAM

Dimensions in mm



A.1.13 30CPQ080

International
IOR Rectifier

30CPQ080
30CPQ100

SCHOTTKY RECTIFIER

30 Amp

Major Ratings and Characteristics

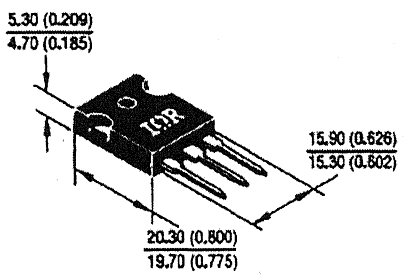
Characteristics	30CPQ...	Units
$I_{F(AV)}$ Rectangular waveform	30	A
V_{RRM}	80/100	V
I_{FSM} @tp = 5 μs sine	920	A
V_F @ 15Apk, T_J=125°C (per leg)	0.67	V
T_J	-55 to 175	°C

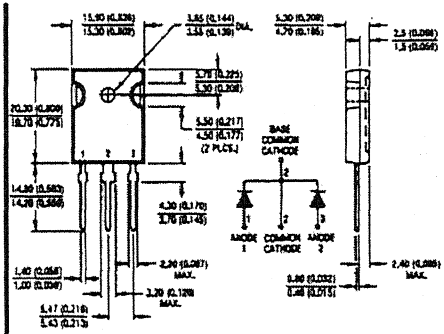
Description/Features

The 30CPQ... center tap Schottky rectifier has been optimized for low reverse leakage at high temperature. The proprietary barrier technology allows for reliable operation up to 175° C junction temperature. Typical applications are in switching power supplies, converters, free-wheeling diodes, and reverse battery protection.

- 175° C T_J operation
- Center tap TO-247 package
- High purity, high temperature epoxy encapsulation for enhanced mechanical strength and moisture resistance
- Low forward voltage drop
- High frequency operation
- Guard ring for enhanced ruggedness and long term reliability

CASE STYLE AND DIMENSIONS





Conforms to JEDEC Outline TO-247AC (TO-3P)
Dimensions in millimeters and inches

A.2 Standard Wire Gauge Sheet:

SWG No.	Dia. inch	Dia. mm	SWG No.	Dia. inch	Dia. mm	SWG No.	Dia. inch	Dia. mm
7/0	.500	12.7000	13	.092	2.2368	32	.0108	0.2743
6/0	.464	11.7856	14	.080	2.0320	33	.0100	0.2540
5/0	.432	10.9728	15	.072	1.8288	34	.0092	0.2337
4/0	.400	10.1600	16	.064	1.6256	35	.0084	0.2134
3/0	.372	9.4488	17	.056	1.4224	36	.0076	0.1930
2/0	.348	8.8392	18	.048	1.2192	37	.0068	0.1727
1/0	.324	8.2296	19	.040	1.0160	38	.0060	0.1524
1	.300	7.6200	20	.036	0.9144	39	.0052	0.1321
2	.276	7.0104	21	.032	0.8128	40	.0048	0.1219
3	.252	6.4008	22	.028	0.7112	41	.0044	0.1118
4	.232	5.8928	23	.024	0.6096	42	.0040	0.1016
5	.212	5.3848	24	.022	0.5588	43	.0036	0.0914
6	.192	4.8768	25	.020	0.5080	44	.0032	0.0813
7	.176	4.4704	26	.018	0.4572	45	.0028	0.0711
8	.160	4.0640	27	.0164	0.4166	46	.0024	0.0610
9	.144	3.6576	28	.0148	0.3759	47	.0020	0.0580
10	.128	3.2512	29	.0136	0.3454	48	.0016	0.0406
11	.116	2.9464	30	.0214	0.3150	49	.0012	0.0305
12	.104	2.6416	31	.0116	0.2946	50	.0010	0.0254